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INDIA METEOROLOGICAL DEPARTMENT

HANDBOOK

OF

CYCLONIC STORMS IN THE BAY OF BENGAL

(FOR THE USE OF SAILORS)

BY

SIR JOHN ELIOT, M.A., F.R.S., C.I.E.

(ABRIDGED)

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FOREWORD

The first edition of the Handbook of Cyclonic Storms in the Bay of Bengal by Sir John Eliot was published in 1890. The object of the publication was to give for the information and guidance of sailors facts of observation and results of study of storms in the Bay of Bengal. The last chapter gave practical hints to sailors to detect the formation, development and movement of storms.

The second edition of the book was issued by Sir John Eliot in 1900, incorporating later information and various suggestions for improvement received in the intervening years. The most important addition in the second edition was a chapter giving briefly the chief features of the winds, weather and currents in the Bay month by month.

The second edition has been out of print for about a quarter of a century. Although the question of bringing out a revised edition of the work, completely re-written in parts, has been under consideration for some time, other work has stood in the way of accomplishing it. The pressing demand for information about weather and storms in the Bay of Bengal which has now arisen on account of the war, has led to the preparation of this abridged edition of the Handbook. The facts given in it are as true today as in the last century, and require little modification. All references to meteorological instruments and methods of observation have been left out, as well as accounts of currents in the Bay, as fuller information is available elsewhere. The last chapter containing hints to sailors has also been omitted. The facts about the weather and storms in the Bay in each month of the year, and accounts of some typical cyclones have been given as briefly as possible. It is hoped that this abridged and slightly revised edition along with the publication "Winds, Weather and Currents on the Coasts of India and the Laws of Storms" will be useful not only to the seaman, but also to the airman and the meteorologist.

C. W. B. NORMAND,
Director General of Observatories.

Poona,
September, 1943.

HAND-BOOK OF CYCLONIC STORMS IN THE BAY OF BENGAL FOR THE USE OF SAILORS

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Sir John Eliot.

(ABRIDGED)

CHAPTER I.—INTRODUCTION

The chief object of this volume is to give the mariner who navigates the Bay of Bengal an account of the dangerous storms that occur in it, to state and explain the signs and indications by which he may recognize when he is approaching a cyclone, or that a cyclone is forming in that part of the Bay which he is traversing, and to furnish him with information and methods by which he may ascertain sufficiently for all practical purposes the bearing or direction of the storm centre, and the path of any cyclonic storm he may meet with in the Bay.

By following these or similar instructions he will, in the great majority of cases, if not in all, when he is involved in cyclonic weather in the Bay of Bengal, be enabled to avoid the inner storm-area of dangerous winds, and fierce squalls and rapid shifts of wind.

I may here point out that my aim throughout the book has not been to give hard and fast rules, the observance of which will enable any seaman to pursue the safest course when he meets with a cyclonic storm in the Bay of Bengal. I do not believe it is possible to draw up rules which will be of use without the co-operation of the full intelligence of the person who wishes to employ the experience embodied in any series of rules drawn up for his guidance.

Hence throughout the book I have endeavoured to give reasons for every rule in the hope that I may enlist the intelligent co-operation of all who read it. The knowledge of many of the more important features of cyclone movement, development, and decay is as yet very imperfect, and it is mainly by the intelligent observation of those sailors who chiefly experience the birth, development, and movement of the cyclonic storms in the Bay of Bengal that further increase of our knowledge will be made. They supply the raw material for meteorologists to consider, discuss, and embody in rules for guidance.

It is hardly necessary to remind sailors that the storms which are met with in the Bay of Bengal are occasionally of excessive violence. Formerly when little or nothing was known of the laws of storms, they caused frequent grave destruction to shipping. Disasters still occasionally happen, and, in some cases at least, may be traced to neglect of ordinary precautions, or to disregard of the accumulated experience of the past.

The sun is the great source of energy or the motive power acting directly or indirectly on the atmosphere.—One of the more important enquiries that any one studying the weather has to take up, is to find out what is the agent or motive power which supplies the energy that puts large masses of air into rapid motion and maintains the motion for considerable intervals of time. For example, in many of the larger cyclones of the Bay, a mass of air, 100 miles at least in diameter and probably not less than a mile in height, is caused to move at a rate which averages at least 40 (if not 60) miles per hour. The mass of air put into this rapid motion weighs as much as half a million 6,000-ton ships at the least and moves more than three times as quickly. It should also be remembered that this amount of motion has not only to be gradually given to the mass of air, but that it is frequently continued

for several days against the various resistances offered to the moving mass of air. How effective and powerful these resistances may be in certain cases is shown by the fact that the Backergunj cyclone, one of the largest of the nineteenth century, was completely destroyed by the resistance of the hills of eastern Bengal in the space of a few hours. The amount of power necessary to maintain the motion after it has been generated is difficult to estimate, but is certainly equal to the engine power that would be necessary to drive some hundreds of thousands of 6,000-ton steamers at the rate of 12 miles per hour. Whence is this power, this energy, derived?

The sun is an enormous reservoir of heat which it is giving out continuously. The heat thus radiated is propagated through space, and produces at the surfaces and in the atmospheres of the planets all the changes that heat is capable of effecting. Meteorologists almost universally assume that the sun is directly or indirectly the agent or the motive power, which produces all the larger changes or motions in the earth's atmosphere. It is its energy alone which maintains the steady trade-winds from year to year and the periodic monsoon winds of India, and which sets in motion those fierce destructive hurricanes or cyclones of the Indian and Atlantic Oceans that are the dread of the sailor.

Character of air motion on large scale.—There are certain peculiarities in air motion which it is desirable to explain.

When there is prolonged motion in such a mass as the open air, if we consider the onward motion of any portion, it is evident that the air in front of that portion must be also moving onwards and vacating the space to be filled by the advancing air, and also that the air behind the advancing portion will move forwards to fill up the space vacated. Hence the motion of air at any point also necessarily implies that the air is moving in front and behind. And the same will be true for these two portions of air in front and rear, and so on. The same argument continued will show that the only prolonged air-motion possible is one which returns finally into itself or motion in a circuit or closed path. It resembles to some degree the motion of a continuous band such as is used for driving machinery or that of the electrical current (as it is usually considered) in a continuous wire. When the air is moving on the large scale it is hence in all cases moving more or less in a circuit.

Air motion of expansion and contraction.—Another kind of motion of air that may occur is such as happens when a hollow ball of thin India-rubber, etc., is held near a fire. The air inside is heated and the elastic and flexible cover is driven slightly outwards, so that the air inside occupies a slightly larger volume than before. In ordinary language the air expands and motion of some kind is necessary for expansion. The motion, however, of the air in this case is quite different to that which would occur if the bladder were to burst. Any portion of air out in the open is in reality surrounded by a wall of air which, like the membrane of the ball, can be thrust outwards by the expansive action of the air within it when heated, so that the given portion of air occupies a larger volume than when it was colder. This takes place as a necessary result of heating. There is no doubt that this motion of expansion by heating and therefore also of contraction by cooling occurs on a large scale in nature. It is very probable, if not quite certain, that one of the daily effects of the sun's heat is to cause an upward expansional motion of this kind (with perhaps slight horizontal movement, especially between sea and land and between plains and mountains) which is followed by contraction at night as the air cools down again. The expansion is of course due to, and accompanies, changes of pressure. Where the action of the sun is large and regular, as in the tropical regions, the motion goes on with great regularity from day to day, and gives rise to the very uniform changes in the height of the barometer known as the diurnal tides or diurnal oscillation of the barometer.

Motion of small masses of air through the atmosphere, such as perhaps occurs in squalls, nor'westers, dust-storms, etc.—Another way in which it is possible that a mass of air may move may be compared to that of a cannon ball. The given mass of air may be, from some cause or other (perhaps suddenly or impulsively), set in violent motion and force its way through the almost quiescent air in front of it driving it aside whilst the air closes up again behind it. There are some reasons for believing that the dust-storms in upper India and the brief wind-squalls which occasionally

occur at sea during cyclonic storms may be partly, if not entirely, motion of this kind.

Hence we see that so far as we have considered the subject of air motion in its simpler aspects, the motion of large bodies of air may be either—

(i) The slight motion accompanying expansion or contraction due to heating or cooling of the mass of air.

(ii) The onward motion of a mass of air which has been put into rapid motion, and forces or ploughs its way unbroken through a stagnant or comparatively slow moving mass of air.

(iii) Motion of large masses of air in a circuit or circulation. This may be—

(a) simple, as in the case of the trade-winds,

(b) complex, as in the case of cyclones or when the motion is usually termed vorticose, which case remains yet to be considered.

There may also be any combination of the above motions. This frequently happens in the cases of No. ii and No. iii (b).

The most important case of combination of the above motions is that which occurs in all cyclonic storms.

Air motion in cyclonic storms.—This complex form of motion arises when more or less violent actions occur over an area or centre of disturbance. Thus, for example, when a very large forest is on fire, the heated air over it rises and the air flows in towards it from all sides. The air which rises up after it reaches a certain height tends to spread out and to move away in all directions. For reasons which are partly explained below, the inflow near the surface of the earth to the heated air does not take place directly, but by a species of spiral or revolving motion, forming whirls, such as are very common in water motion, even on the smallest scale. The air is in such a motion drawn in to the centre, but not directly. It moves round the centre of the disturbance and at the same time moves towards the central area into which it is drawn and passes upwards. Hence, when such a disturbance is started, the air at and near the earth's surface rushes towards the centre from all directions, and the actual motion which results from such a rush towards a central area of disturbance and uptake is always rotatory. In the case of very small whirls such as give rise to waterspouts at sea, the whirling or rotatory motion is probably due to the fact that the air from different directions rushes in with slightly different velocities or rates of motion. In the case of the enormous whirls which form cyclonic storms this is not the chief cause in operation. This is due to the fact that the air is connected with the earth, which is a moving body. Hence, when the air is in apparent motion, it is actually moving with respect to a body which is itself in motion.

Now, air, when it is moving over the earth's surface, is connected with, and moving with respect to, a body itself in motion. And, so far as one part of the earth's motion is concerned, viz., the motion round its axis once a day, the rate of motion differs at different parts of the earth's surface, being greatest at the equator and diminishing to nothing at the poles. It can be shown mathematically that the effect of the air moving over the earth's surface is almost exactly equivalent to the supposition that the earth is at rest and that there is a force which is always (in whatever direction the air may be moving) tending to turn it in the northern hemisphere to the right hand of its line of motion. Thus it is that the air moving northwards from the equator up the Bay of Bengal or Arabian Sea in the open sea is bent more and more to the right hand or east, and hence that the wind direction in passing northwards from the equator up the Arabian Sea during the south-west monsoon changes from south through southwest to westsouthwest. This is of course only out on the open sea, where there are no obstructions to modify this course.

Hence, if any disturbance arises in the air which tends to draw the air in from all directions, the air which moves directly towards it from all quarters will be drawn aside and have its direction continuously changed as it advances towards the centre, and from whatever direction, it will be deflected towards the right hand.

It is not possible to represent such a motion by a single diagram. In a vertical section through the centre the motion would be somewhat as follows :—

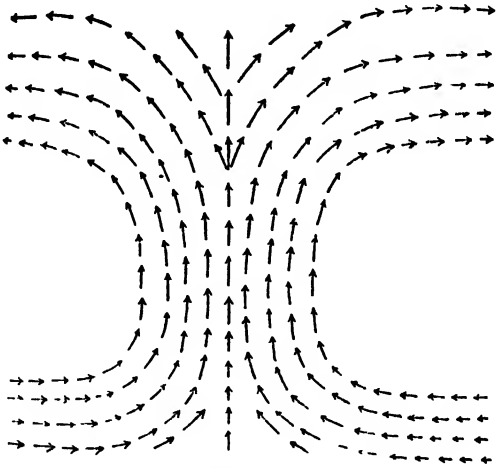

FIG. 1.

This, however, represents one feature of the motion and by no means the most important part. The air is drawn into the centre, but is not drawn directly to it. The particles move by a kind of spiral path to the centre figured as below, and hence tend to carry bodies inwards by such a path—

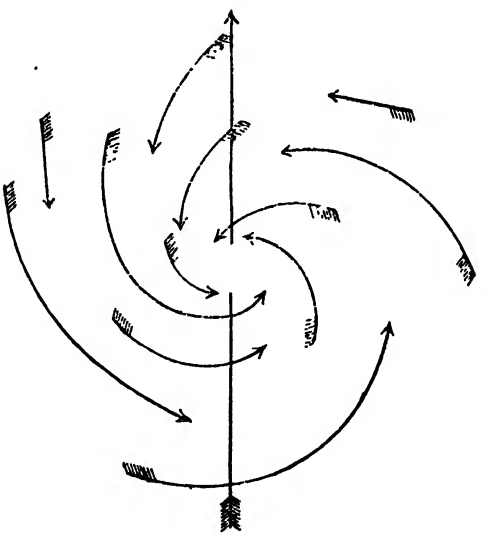

FIG. 2.

It is most important to remember that the air moves in this manner when there is a central disturbance giving rise to a rapid motion of the wind about the centre and of indraught towards the centre. It has been stated by several of the older meteorologists that the air moves round the centre in a circle as a point on the rim of a wheel moves round the axle, and that, therefore the direction of motion of the wind is at right angles to the direction, or bearing of the centre. Every cyclonic storm that is investigated, in whatever part of the world it occurs, furnishes fresh evidence of the error of Piddington, Reid, and others on this point and confirms the spiral theory of the motion of the air in cyclones. Such a motion of the air is called a cyclonic circulation and *may be very feeble, or it may be so violent as to constitute a dangerous storm.*

Cyclonic circulations have certain general features, the chief of which should be carefully remembered—

1st.—The barometer is always low at or near the centre and is high on the outskirts or outer edge, of the circulation, and diminishes as we proceed from the outskirts to the centre. The fall is also usually most rapid near the centre.

2nd.—The air near the earth's surface not only moves round, but is drawn in towards the centre and moves always in the same direction with respect to the centre in the northern hemisphere. The air moves round in a direction which is the opposite to that in which the pointers of a watch move, so that, roughly speaking, to the east of the centre, southerly winds prevail, to the north, easterly winds, to the west, northerly winds, and to the south, westerly winds. Hence the direction of the wind in a cyclonic storm indicates to an observer in what part or quadrant of the storm area he is. This motion is usually known as the cyclonic motion of the wind in the northern hemisphere, and is frequently denoted thus—

3rd.—At and near the centre over which the air is ascending there is much developmet of cloud, and frequently heavy rainfall, whilst in the outskirts, where there are descending currents, fine clear dry weather is the rule, and there is a gradual transition from the one kind of weather to the other as we pass from the outskirts to the centre and *vice versa.*

The readers should hence remember that to a meteorologist what is called a barometric depression, or a low, over an area relative to neighbouring districts and a cyclonic circulation are similar terms and suggest the same kind of air motion or disturbance.

Motion of the air in an anticyclone.—The same general kind of motion about a centre, but in the reversed direction, can be produced in various ways, as for example, by great cold or by the fall of snow over a large area. The effect of the cold could be to produce a descending current, and hence near the surface of the earth the air would move away, the motion not taking place directly from or round the centre, but in a spiral or vorticose manner, and above the air would stream in by a similar kind of path to feed the descending current.

The chief features of such a motion are the opposite of those of a cyclonic circulation.

1st.—The barometer is highest near the centre and gradually falls as we pass from the centre outwards.

2nd.—The spiral motion of the air about the centre is performed in the opposite direction to that already described, or, in other words, the air moves round in the same sense or direction as the hands of a watch. The direction is usually shown in the following manner :— 

Such a motion of the air is termed anticyclonic and the whole phenomenon an anticyclone. The motion of the air in an anticyclone is very rarely violent and never so in tropical seas.

General character of the larger barometric changes in the Bay of Bengal—

(A) Except during the existence of the larger and more severe cyclones the barometric changes in the Bay of Bengal are always small in amount and take place very steadily and gradually. There is none of that rapid and large fluctuation of the barometer in the Bay of Bengal such as occurs in England or the North Atlantic Ocean if the weather be the slightest unsettled. A fall of a tenth of an inch in 24 hours in any part of the Bay is certainly less frequent than a fall of half an inch, and probably less frequent over the greater part of the Bay than a fall of an inch, in the same interval in England or the British Seas.

(B) The general principle is that in cyclonic disturbances the barometer usually rises more quickly in the rear of the storm than it falls in front. An equally important feature in which the changes of pressure in the Bay of Bengal differ from those usually experienced in the British Seas or temperate regions is, that there are large regular movements of the barometer which have absolutely

nothing to do with stormy or disturbed weather, and which consequently must be allowed for before we can obtain the changes of pressure caused by approaching bad weather or by a cyclonic storm. One of these is the daily tides or diurnal motion of the mercury in the barometer which goes on with the same regularity in fine as in unsettled weather. It is a kind of pulsation or oscillation which continues amidst all the changes and variations of weather in India, and is performed with such regularity that if it were not that it is occasionally mixed up with, and obscured by, other changes, it might be used to determine the time of day approximately. As this movement goes on equally in fine as in stormy weather, it can have nothing to do with the production of the latter, and hence this regular change must be left out of account entirely in using the barometer as an indicator of stormy weather.

The table below gives for the Bay as a whole the mean hourly values of the diurnal variation of pressure from the mean of the day in millibars.

Hours ..	0	1	2	3	4	5	6	7	8	9	10	11
mb. ..	+0·3	—0·2	—0·7	—1·0	—1·0	—0·6	0	+0·6	+1·2	+1·5	+1·5	+1·1
Hours ..	12	13	14	15	16	17	18	19	20	21	22	23
mb. ..	+0·5	—0·2	—0·8	—1·3	—1·4	—1·2	—0·8	—0·3	+0·3	+0·7	+0·9	+0·7

Again in the months of June, July and August, when the southwest monsoon is fully established, there is always a difference of pressure, averaging nearly four-tenths of an inch, between the south and the head of the Bay. Hence the barometer on board a steamer going up the Bay from Galle to Calcutta will usually fall during the three or four days of the passage four-tenths of an inch in consequence of the ordinary weather conditions of the period. A smaller fall than this would probably mean much finer weather than usual, and a larger fall that a very strong monsoon was blowing over the whole of the Bay, or a cyclonic storm was in progress near the head of the Bay.

It may also be noted that even after due allowance is made for the daily oscillation, it is found that the atmospheric pressure or the height of the barometer is never absolutely steady, but, like the bob of a pendulum suspended by a long wire or string, is always moving or oscillating through small distances. Thus, in the finest and most settled weather in India, the barometer rises for a short period, usually about one to three days, and then falls for a similar period and rises again, and so on. These small oscillations appear to be almost as essential a part of the ordinary atmospheric changes as the diurnal tides, and hence are almost independent of the weather. By far the larger number of disturbances, however, appear to originate during the periods of falling barometer and hence, as might be expected *a priori*, the unsettled weather, which precedes cyclonic storms, tends to occur during the falling, rather than the rising, portion of these general barometric movements or oscillations over India.

(C) The barometric changes are, as a rule, much smaller in the south than in the centre and north of the Bay. For the barometer at the entrance of the Bay in ordinary weather does not vary more than two-tenths of an inch all the year round, rising and falling between 29.75 in. and 29.95 in. (leaving out of account the daily barometric tides). Whereas in the extreme north of the Bay (without taking into account the large movements during cyclonic storms) the barometer falls from an average of 30.05 in. in January to an average of 29.50 in. in July, or through nearly six-tenths of an inch. Hence the total annual range or movement of the barometer is very small in the south of the Bay and increases in amount northwards.

(D) The barometer in the Bay of Bengal during the period, May to November and December, to which cyclonic storms are almost entirely confined, seldom falls

so much as a tenth of an inch, and very rarely so much as ·15 inch in 24 hours at the same place unless a cyclonic storm is forming in the neighbourhood of, or is advancing towards the place of observation.

(E) The steadiness of the barometer in the tropics, as compared with the temperate regions, is, it may be stated, mainly due to the slow rate at which the velocity of the rotation of the earth's surface alters in the tropics with increasing latitudes. The barometer in the Bay of Bengal rarely rises a tenth of an inch in 24 hours unless a cyclonic storm is either filling up near the place of observation or has been advancing away from it. It is not so necessary to give data for this statement, as the principle is of much less importance than the preceding. The data, however, will help to establish the general principle of the smallness of the daily barometer changes in the Indian seas, and hence further confirm the data in the preceding paragraph. They also show that rapid rises of the barometer are more frequent in the Bay than rapid falls. This is, of course, only one phase of the general principle that the barometer rises more quickly after the passage of a cyclonic storm than it falls during its approach, or that the barometer rises more quickly in the rear of a storm than it falls in front.

(F) The preceding principles (more especially C and D) hence establish the following important rule :—

If the barometer in the Bay of Bengal during the cyclonic season lasting from May to December falls more than .15 in. in the north of the Bay—or more than ·10 in. in the centre or south of the Bay in 24 hours,— that is, if the difference between the reading of the barometer at the same place and at the same hour on two consecutive days differs by amounts exceeding ·10 in. in the centre and south of the Bay —or ·15 in. in the north of the Bay,—it may be accepted as an almost certain indication that a cyclonic storm is forming in the neighbourhood, or that a cyclonic storm of considerable or great intensity is approaching it.

(G) An equally valuable and important principle is the following :—

It is very rare for the barometer to fall in the north of the Bay of Bengal more than two-tenths of an inch (·20 in.) below its normal height or more than ·15 in. in the centre of the Bay, and if it does on board a ship at any place in the north or centre of the Bay, it indicates that pressure is below the normal or ordinary pressure by that amount at least, and is an almost certain indication that a cyclonic storm has formed, or is forming in the Bay the position of which can be ascertained from other indications.

An important principle of conversion of energy, viz., that the intensity of action varies inversely with the time of action. In the case of the lever, a feeble force acting through a considerable distance, may exert or give rise at the other extremity of the lever to a large force acting through a small distance, but whatever increase of force is gained by its use, the distance through which it acts is proportionately diminished, or, as it is usually expressed, what is gained in force is lost in distance. In considering the changes or actions we are now contemplating, we have to remember that there are, as in the case of the lever, two elements. These are, in the present case, intensity of action and the duration of the action. It is almost self-evident that in the case of any transfer of energy or performance of work by machinery, whatever we can gain in one of these elements is lost in the other. These remarks will hence illustrate the principle that in any conversion of energy what is gained in intensity is lost in time, or that the duration of the action diminishes at the same rate as the intensity increases.

Hence it is that the energy of the electrical discharge of a thunderstorm is very small indeed. It can produce very violent effects depending upon mere intensity of action, but the duration of action of a flash of lightning is so excessively small that the amount of work it can do is small and it has been shown most conclusively by distinguished men like Faraday and Tyndall, that a few pounds of coal contain more energy and can do more work than the whole of the electricity generated during a thunderstorm.

Applications of the preceding principles to the processes of evaporation and condensation.—These remarks, it will be seen, have a most important bearing on our subject.

The sun in evaporating water does a certain definite amount of work on each pound of water when changing its state into aqueous vapour. When the aqueous vapour is

re-converted by any method into water and returns to the earth's surface, it yields up the energy given to it by the sun, in virtue of which it can do an amount of work practically equal to that done by the sun in evaporating it.

The most important question, in connection with this re-conversion of the aqueous vapour into water is the rate at which it takes place—that is whether the action is like that of the watch or the pile hammer after it has been acted on by man. The following reasons will show that it resembles that of the pile hammer rather than that of the watch :—

It is believed, from a large number of experiments that have been made (as for example measuring the depth of water evaporated in tanks in India, etc.), that the amount of heat energy which comes from the sun and falls on every square foot of surface of the Bay of Bengal does on the average the work of evaporating a tenth of an inch of water in one day or nearly eight ounces of water. According to some the amount may be as much as one-fourth of an inch or upwards of a pound of water per square foot of surface or about seventy-five million tons of water per square degree of surface of the Bay of Bengal. We shall assume for the purposes of the argument that the evaporating power of the sun per square foot of surface is one quarter of an inch and this may hence be taken as a measure of the sun's activity at and near the earth's surface.

When it falls upon a dry land surface it heats it rapidly, and the heated surface then imparts a portion of its heat to the air by the same kind of process and motion as that which takes place when water is boiled in a kettle over a fire. It is by this kind of heating mainly that the air becomes hotter during sunny days, and not by the direct action of the sun. On the other hand, when the sun's heat falls upon the surface of water, or very damp soil, its action is almost entirely confined to evaporating the surface water. Hence the effects of sun's heat at land and sea are essentially different. In the latter case, it is continuously during the day adding to the amount of aqueous vapour in the air, but produces hardly any change of temperature in the air itself. In the former case, or in the interior of a country like India, the sun's action during the day produces indirectly very considerable changes of pressure, density, and temperature, and as the air is not contained in a closed space and is free to move, these changes are accompanied by a very considerable amount of motion, in part ascensional and in part horizontal. Hence it is over the land that many of the changes take place which initiate winds and changes of winds For example, land and sea breezes are due to the rapid heating of the land in the day time as compared with the sea, and its equally rapid cooling at night.

And it is evident that if there were no action due to the varying amount of aqueous vapour in the air or to the processes of evaporation and condensation, the chief cause of the motion of the air or of winds would have to be sought for solely in the different heating effects in different latitudes or on land and at sea. Such actions are sufficient to explain satisfactorily the trade winds, land and sea breezes, the hot dry winds of upper India in April and May, etc. But these are all comparatively feeble winds, and not in any way comparable in force to the violent hurricane winds of cyclonic storms in the Bay of Bengal, and it is therefore evident that these strong storm winds must be due to some other action than the heating of air by contact with surfaces of land exposed to the powerful rays of a tropical sun.

There is only one known action which appears to be adequate to explain these winds. In all the larger and more violent cyclonic storms of the Bay of Bengal there is always heavy, and almost continuous concentrated rain over the inner storm area, and frequent rain squalls in the outer storm circle, whilst beyond the area of disturbance the weather is fine and clear for very considerable distances to the north, east, and west. Judging from the rainfall that occurs during the passage of cyclonic storms across India, it is almost certain that near the centre rain falls at the rate of 1½ to 2 inches or even more per hour. The amount of rain at any place not only depends upon its intensity, but upon its duration, which in cyclonic storms depends upon the magnitude of the storm and the rate of its motion. Rainfalls of from 5 to 10 inches in 24 hours at places passed over by cyclonic storms are quite common in India after they reach land. Rainfalls of from 10 to 20 inches in 24 hours are of comparatively frequent occurrence, and of from 20 to 30 inches of occasional occurrence. Hence it is quite within the mark to assume as a fair average estimate that 10 inches of rain fall over the inner storm area of a large and intense cyclone during every 24 hours of its existence as a violent storm.

Taking the estimate of the sun's power per day to be equivalent to that required for the evaporation of a depth of one-quarter of an inch of water, it is evident that over the storm area forty times as much water would be condensed and poured down as rain, as the sun is able to evaporate in the same interval, that is, in this case the work of condensation would go on forty times as rapidly as that of evaporation goes on in the Bay in fine sunny weather. Hence also, forty times as much energy would be given out by the condensed aqueous vapour to the surrounding air as could be given by the direct action of the sun. In other words, there is in such a storm an action going on, and a conversion of energy which is very much more intense and powerful than the direct action of the sun, and can therefore produce much more rapid and greater changes and motions. If the rainfall be heavier than 10 inches per 24 hours, the action will be proportionately more intense.

The energy given up during condensation appears to be communicated to the air directly and produces rapid increase of its motion. The aqueous vapour in this case may hence be compared to the coal which is necessary to heat the boiler of a steam-engine or steam-vessel. Each of them, i.e., coal and aqueous vapour, contains a certain amount of energy per pound of mass. In the one case the coal gives up its energy, by the process of burning or combustion, to the water or steam in the boiler, in virtue of which it is able to move the mechanism of the vessel. In the second case the aqueous vapour gives up a portion of its energy whilst being converted into water by the process of condensation, and communicates that energy to the air which is hence put into violent motion.

There are several important features in this transfer of energy which should be remembered :—

First.—It is a direct action or effect upon the air and not an indirect one, and is hence different from the heating of the air during the day which is due indirectly to the sun heating the earth's surface. Practically the whole of it is hence utilized in producing changes in the motion of the air.

Second.—It is continuous and not intermittent like the sun's action on the earth or the surface of water and is not suspended at night.

Third.—It is, in the case of heavy cyclonic rainfall, a very much more intense action than the direct action of the sun. If we call the ordinary action of the sun a sun-power, this action might be twenty, fifty or even one hundred sun-powers.

Fourth.—It is given out to a very limited mass of air compared with that acted upon directly by the sun. The sun's action, for example, extends almost equally over the whole of India and the Bay, and its power differs comparatively little at different places during the hot weather and rains. The action of rainfall on the contrary is local and hence produces a very large effect on a limited mass of air (or a very large local disturbance which is the primary feature of cyclonic storms), and very little at a distance of 200 or 300 miles. It hence gives rise to very great differences of condition at moderate distances, and this, it is hardly necessary to point out, is the most essential feature of a large local disturbance.

In order to ascertain the chief motive power of cyclonic storms or the energy given out during the process of condensation of aqueous vapour and of rainfall, it would be necessary for a complete enquiry to ascertain the conditions under which this action of rainfall takes place, and more especially the conditions necessary for the peculiarly concentrated and localized heavy rainfall that accompanies and maintains cyclonic storms. This, however, is not necessary in the present little work, as the chief object of these remarks has been to direct the attention of the sailor to the real motive power, and hence by inference to suggest that electricity, or temperature differences are utterly inefficient, and not to give a full account of the various theories that have been suggested at different times to explain the origin and phenomena of cyclones.

In the preceding paragraphs a very brief explanation has been given of what may be termed the motive power of cyclones. It is not, of course, a complete explanation of all the actions accompanying cyclones. To return to our illustration : it is not merely sufficient to have coal in order to produce rapid motion of a ship, but it is absolutely necessary to have a complicated apparatus and men to guide and control that apparatus or machinery. The machine or steam-engine is as necessary for the conversion of the energy of the coal into the motion of the ship as the coal itself. Similarly, in the case

of cyclones, whilst the motive power is derived from the condensation of aqueous vapour, various conditions have to be fulfilled in order that this motive power may originate and maintain a cyclonic storm.

Process of condensation of aqueous vapour in nature.—Since the air can contain less vapour in the invisible state at a lower than a higher temperature, if a given quantity of air be taken and be cooled down far enough, it will arrive at a state when it is saturated, and if it be cooled still further, it cannot contain that amount of vapour in the invisible state, and the surplus will be condensed into small globules of water, forming a visible white mass. The process of condensation in nature on the large scale is hence always due to cooling the air below the temperature of saturation by some process. There are various ways in which this may occur, but it will be sufficient to mention two. The first is by the air near the earth's surface on dry calm cold nights being cooled down by contact with the earth's surface, which cools rapidly by giving out the heat it has absorbed during the day. In this case if the cooling be sufficiently great, the air near the earth's surface will fall below the saturation point and condensation will take place, and mist or fog be formed. This method never gives rain, as it occurs through too small a depth of air for the formation of large drops and therefore for rainfall. The second, and by far the most general cause, is due to the cooling of air that is rising higher and higher above the earth's surface. An ascending column of air is the most fruitful source of rain that occurs in nature. The reason of this is not difficult to understand. The given mass of air in rising up passes through air which presses less and less vigorously on it as it rises. In other words, the external pressure on it diminishes. The air is then able to swell out, pushing aside the surrounding air to a large extent as it rises. But in pushing aside the outside air it exerts force through a distance or does work. As a body doing work necessarily loses some power of doing work or energy, the air in expanding during its ascent loses energy, and the energy which it loses is not chemical energy, electrical energy, etc., but heat energy. It in fact acts on the same general principle that lies at the root of the action of the steam-engine. If, then, a portion of it by rising and expanding cools down, and if this motion of ascension proceed far enough, the air will cool below its saturation point and some of its invisible vapour will be converted into visible globules forming a cloud.

Rainfall.—The enormous energy of cyclones in the Bay of Bengal is almost entirely derived from the change of the aqueous vapour present in the air into rain by the process of condensation. As the largest and most intense cyclones in the Bay of Bengal are far more severe and intense than storms in the temperate regions of the Atlantic Ocean, and have features which are either absent or are not conspicuous in those storms, as for example, storm waves, calm centres, etc., this would naturally suggest that the rainfall in tropical cyclones is almost certainly much greater than ever occurs in the storms of the North Atlantic Ocean. This cannot be proved by actual measurement of rainfall at sea, as no satisfactory method has yet been generally introduced for measuring rain on board ships. The descriptions of cyclonic storms in tropical seas, as given in the logs of vessels, however, abound in expressions evidencing the extraordinary intensity of the rainfall. The following are quoted from logs which have been sent in during recent storms in the Bay of Bengal :—"Terrific rain," "Sheets of rain," "Torrents of rain," "Blinding rain," "Continuous heavy rain," "Steady hard rain," "Thick rain," "Incessant rain," "Thick blinding rain," "Deluge of rain", "Rain coming in a solid mass," etc.

CHAPTER II.—NORMAL WEATHER IN EACH MONTH IN THE BAY OF BENGAL.

The present chapter gives a brief description of the weather usually experienced in the Bay of Bengal during the year.

The Bay of Bengal is included within the larger area known as the Indian monsoon region in which winds from opposite directions prevail during the two divisions of the year known as the northeast monsoon (or season of northeast winds in the Indian seas) and the southwest monsoon (or season of southwest winds in the Indian seas).

The Northeast monsoon.—The northeast monsoon conditions are most fully established in the months of January and February.

In these months pressure is highest in northern India and central Asia (including Persia), decreasing southwards to the south of the equator and thence increasing again southwards to Lat. 25° or 30° in the Indian Ocean. The general air movement in the Indian seas and India in these months is from north to south. These northerly winds in the open seas are deflected by the action of the earth's rotation to the right and hence are from northeasterly directions. These northeast winds during this period are similar in their origin to the northeast trades in the Atlantic and Pacific Oceans, the chief difference being that the latter are permanent winds, whilst the former are seasonal winds only.

As pressure is always higher in the centre and south of the Indian Ocean than in and near the equatorial belt, the air movement in these regions is always from south with a deflection from east due to the earth's rotation (which is to left in the southern hemisphere). These southeast winds are permanent and not seasonal, and are the southeast trades of the Indian Ocean.

The intermediate area between the southeast trades of the Indian Ocean and the northeast winds of January and February in the Indian seas is a region of light unsteady winds and calms, much rain, frequent thunderstorms, and squalls. It corresponds to the Doldrums of the Atlantic and the Pacific Oceans.

As these northerly winds over the Indian seas are the continuation of an air movement from the interior of India and the countries to the north and west, they are comparatively dry and cool. Hence during their full prevalence dry cool weather with little or no cloud obtains over the greater part of the Bay of Bengal. Conditions begin to change in the latter half of February or the first half of March due to the increasing influence of the sun or of the solar heating action which gives rise to a ready and continuous increase of temperature over the whole Indian land and sea areas. The increase is considerably greater over the land than over the sea. Hence the air begins to draw into the land from the neighbouring seas. This is chiefly exhibited in February and March in the Bengal, Orissa, and Ganjam coast districts and neighbouring portions of the Bay, where light to moderate southwest winds set in and prevail in increasing strength.

It should be carefully noted that these southwest winds are local winds, restricted in March to a small part of the north and northwest of the Bay. Over the remainder of the Bay northeast winds continue, but are less vigorous than in January and February. With the increasing temperature and heat of the interior of India in April and May, the local sea winds in the north and northwest of the Bay intensify and also extend over an increasing area seawards as well as landwards.

In March these winds extend over the Bay north of Lat. 18° N. and in April north of Lat. 14° N. South of that latitude light unsteady winds prevail, except over the Coromandel coast district where local southerly winds (long shore winds as they are usually termed) prevail.

Whilst these changes are in progress in the north of the Bay in March and April, other changes of equal importance are initiated in the extreme south of the Bay where westerly winds set in, at first very unsteadily. These westerly winds are not true southwest monsoon winds as the belt of calms and variable winds extend over the eastern half of the equatorial belt at this time. They appear to be mainly due to slightly lower pressure over south Sumatra and the Malay peninsula or to an indraught from the cool sea to the heated island and peninsular areas to the east.

The region in the centre of the Bay between the area of moderate westerly winds in the South of the Bay, and of moderate to strong southwest winds in the north of the

Bay is characterised by light to moderate variable winds, chiefly from northerly directions.

In May the two systems of winds in the north and south of the Bay increase in intensity and extend southwards and northwards, so that west to southwest winds prevail generally over the Bay in that month. These winds, so far as can be judged from the cloud data, are comparatively shallow and do not extend upwards more than perhaps 5,000 feet. As they blow over a sea area at a comparatively high temperature, they are, however, very damp and hence give much showery or rainy weather, more especially in the east and south of the Bay and in Burma, Bengal and Assam. In these land areas the rainfall is chiefly due to the forced ascent of the sea winds in the Bengal and Assam hills and usually accompanies thunderstorms. Occasionally cyclonic storms form and as conditions are favourable to their steady and prolonged development, they are occasionally of the most dangerous type, *viz.*, cyclones with a calm centre and hurricane winds.

The southwest monsoon.—The great change which initiates the southwest monsoon proper in the Bay usually occurs in the last week of May or first week of June. Previous to that change, in the latter part of May and the beginning of June, southeast winds prevail in the Indian Ocean from Lat. 30° S. to the equator and west and southwesterly winds from Lat. 2° or 3° N. to the head of the Bay of Bengal. The intermediate belt over and to the north of the equator is an area of light, unsteady winds with showery weather, thunder squalls, etc. There is hence a clear and marked separation between the two horizontal systems in the Indian Ocean and the Bay of Bengal.

A comparatively sudden change usually occurs early in June, in virtue of which the intermediate belt of light variable winds disappears and a continuous horizontal air movement is established over the whole area from Lat. 30° S. to India and Burma. There is little change in the direction of the mean winds, except in and near the equator, where they veer rapidly from southeast through south to southwest and westsouthwest in passing through the equatorial belt.

This change is accompanied by a large rush of damp air from the Indian Ocean across the equatorial belt into the Bay of Bengal and the Arabian Sea.

One important effect of this is to change the lower air current in the Bay from one of shallow depth (perhaps 5,000 feet) to one of great depth, probably exceeding 15,000 feet. As might be expected the vast inrush of moist air from the south of the Bay gives rise to a very large amount of irregular disturbance, more especially to much rain and frequent squalls.

This action frequently tends to localize and intensify over the centre of the Bay, with the result that the advance of this moist inrush very often gives rise to a cyclonic storm of considerable to great intensity in each sea area.

This change in the character of the air movement over the Bay, ending in the establishment of the southwest monsoon over the Bay and northern India, initiates conditions which are permanent during the next three months, *i.e.*, July, August, and September.

The southwest monsoon currents blow with unabated vigour in July and August and begin to show signs of decreasing strength in September. This decrease of strength is exhibited in various ways. In the first place the current does not advance so far into the interior of India as before, or in other words it gradually withdraws, first from northwest India, next from central India, the United Provinces and Bihar, and afterwards from Bengal. The withdrawal of the current from the land area of northern India is a slow process, usually taking about a month for its completion. The pressure changes accompanying the retreat of the current are especially interesting. The withdrawal of the current accompanies an increase of pressure to the northwest and west, which is an essential part of the whole process.

Metcorological division of the year into four seasons.—The best division of the year in the Bay of Bengal from these conditions is as follows :—

1*st.*—From January to March, when northeast winds of land origin prevail over the whole or greater part of the Bay.

2*nd.*—April and May, during which the winds change to southwest over the Bay. The winds in May are due to local conditions. They change slightly in direction in June and strengthen considerably in the centre of the Bay, due to the change of

their origin from local conditions over the Bay and India to general conditions over India, the Indian seas, and the Indian Ocean.

3rd.—June to September, when southwest winds of oceanic origin hold steadily in the Bay.

4th.—October to December, when these southwest winds of oceanic origin gradually retreat southwards and are replaced by northerly winds of land origin.

These four periods may perhaps be termed—

(1) The northeast monsoon period ;

(2) The May transition period ;

(3) The southwest monsoon period :

(4) The retreating southwest monsoon period.

These terms or divisions will be cited throughout the following chapters.

The following gives a brief description of the weather in the Bay, month by month, during the year.

January.—In this month pressure is usually highest in the north of the Bay and lowest at the entrance to the Bay (*i.e.*, between north Sumatra and south Ceylon). The total range of pressure over the Bay is slightly less than ·15″ giving a gradient for northeasterly winds of barely 1|5. As might be expected from the conditions, winds are slightly stronger in the south than the north of the Bay. Weather is almost invariably fine with light northeasterly winds, clear or lightly clouded skies and a moderate temperature increasing southwards. Weather is occasionally squally off the east Ceylon and north Sumatra coasts due to the forced ascent of the air current produced by the mountains near these coasts. The squalls are, however, rarely severe, but are generally accompanied by much thunder and lightning.

Weather is occasionally feebly unsettled at the head of the Bay when cold weather storms or depressions are advancing eastward across Bengal. Winds then draw round to south or southeast, skies cloud over, and light showers of rain may occur. Weather is almost invariably close and sultry during the march of these storms across Bengal. They are followed by short periods of much drier and cooler weather than usual, moderate to strong northerly winds and bright, clear skies.

The temperature of the air in the shade increases from an average of 68° in the north of the Bay to an average of about 80° in the extreme south. The temperature of the sea surface water, on the other hand, ranges only between 77° in the north of the Bay and 83° in the extreme south.

February.—The general conditions in the Bay are similar to those of the preceding month. Pressure is highest in the north and lowest in the extreme south. The range of pressure averages about ·10″ or two-thirds of that of the month of January. Northeasterly winds continue over nearly the whole area, but they are lighter in the north and centre of the sea than in the previous month, and average barely 2·0 in force at the head of the Bay increasing southwards to force 3 in the south of the Bay.

Southerly winds are more frequent at the head of the Bay than in January. These southerly winds are due to two different actions. The first of these is the passage of cold weather depressions across Bengal, as in January. This is of occasional occurrence in seasons of normal or more protracted cold weather rains than usual in northern India, and of heavy and prolonged snow fall in the Himalayan mountain area. The second is the earlier commencement of the hot weather than usual, following a drier and feebler cold weather than usual. The increasing heat in the interior of Bengal and in Bihar and Chota Nagpur causes the winds to shift round to southerly directions in south Bengal and Orissa and the adjacent sea area particularly in the afternoon.

Weather is almost invariably fine over nearly the whole area. Squalls are of occasional occurrence near the east Ceylon and north Sumatra coasts, but they are less frequent than in January. Weather is also occasionally cloudy and muggy at the head of the Bay during the passage of cold weather storms. This type of weather is, however, less frequent than in January.

The temperature of the air in the Bay ranges from 73° in the north to 80° in the extreme south and differs little from 78° over the greater part of the centre and south of the Bay. It is hence practically unchanged over the southern half of the Bay, but increases rather rapidly in the north near the coasts of Bengal and Orissa.

The temperature of the surface water is slightly higher in the north of the Bay but unchanged over the centre and south.

March.—Pressure is in March on the average of the month slightly higher in the centre than in the south and north of the Bay. The gradients at the head of the Bay and in Bengal are steeper than in February, and the southwest winds in that area hence increase considerably in strength, and also extend to an increasing distance inland and also southwards in the Bay. South winds average 3·0 in force at the head of the Bay, and are strongest off the Orissa and southwest Bengal coasts. Northeasterly winds continue in the centre and south of the Bay and are strongest in the centre of the Bay where they average 2·5 in force, decreasing to about 2·0 in the south of the Bay where they are much feebler and more unsteady than they are in February.

Fine weather prevails as a rule during the month over nearly the whole of the Bay. The air is generally very damp due to the rapid evaporation from the water surface and hence dew is usually deposited on all rapidly radiating surfaces during the night. Winds are much more variable and unsteady in the south of the Bay than in February. Squalls are of comparatively rare occurrence in March off the Ceylon and Sumatra coasts and in the straits of Malacca.

The only area liable to squalls is the head of the Bay near the Bengal and Orissa coasts. Hot weather storms (including thunderstorms, hailstorms, nor'westers, etc.) which form over the hills in Bengal and Orissa travel seawards and sometimes pass into the Bay. The following gives a brief general description of these storms.

The first sign of these storms is a low bank of dark clouds in the northwest, the upper outline of which has the appearance of an arch. It approaches at first slowly, and then more and more rapidly and commences with a strong gust or squall which on land raises clouds of dust. There is frequently heavy thunder and lightning followed by downpours of rain driven by the strong wind. Sometimes the winds blow with almost hurricane force and blow down trees and inflict much damage on houses, etc. These storms are sometimes accompanied with hail. The greatest velocity recorded in these storms at Calcutta is about 100 miles per hour. They rarely last more than two or three hours and are usually followed by cool clear weather during the remainder of the night.

It will hence be seen that these squalls or nor'westers may give exceedingly strong winds approaching in intensity to the hurricane winds of a cyclonic storm, and may give rise to a high sea in the northwest angle of the Bay. They rarely last for more than three or four hours and are of comparatively rare occurrence in March in the north of the Bay.

Gentle breezes between N.W. and N. blow frequently from the land after midnight until morning on the Coromandel coast. These winds are followed by calm or faint variable airs until about noon when a southeast breeze, the long shore wind, sets in.

Temperature increases throughout the month over the whole of the Bay, more rapidly in the north than in the south. It ranges between 78° in the northeast of the Bay and 82° in the west, centre, and south.

April.—During this month pressure falls in the north of the Bay and rises slightly in the south, and is on the mean of the month about a tenth of an inch higher in the southeast of the Bay than in the northwest of the Bay. The gradients are very slight, except near the Bengal and Orissa coasts. Southwesterly winds prevail generally to the north of Lat. 16°N. and are strongest near the Bengal and Orissa coasts where they average 3·5 in force. Near the Arakan coast the winds blow from the west or northwest. Light unsteady winds obtain in the centre of the Bay They average 2·5 in force. Over the south of the Bay also winds are unsteady, winds from westerly and easterly directions alternating, the former becoming permanent before the end of the month. Winds average 2·5 in force in that area except off the west Sumatra coast where they are much stronger.

The chief features of the air movement in the Bay in this month are *firstly* the increasing strength and extension of the southwest winds in the north of the Bay, and *secondly* the weakness, unsteadiness, and variability of the winds in the southern half of the Bay (except near the Coromandel coast).

At the head of the Bay the winds show little variation during the day, but are slightly stronger during the day than the night hours. Near the Coromandel coast, the

day influence is marked. The sea breeze or long shore wind begins at about noon and continues until late at night (usually about 10 P.M.) after which winds veer to southwest or west, falling off considerably in strength.

Temperature increases over the Bay during the month, more rapidly in the north than the south. It is on the mean of the month almost uniform over the whole of the Bay, averaging 84°. The temperature of the surface water is almost identical with this over the whole area.

Hot and sultry weather with light unsteady winds prevails during by far the greater part of the month over the whole area. The air is exceedingly damp and skies frequently clouded. At the head of the Bay nor'westers are of occasional occurrence and are felt sometimes to distances of 60 and 80 miles from land. Thunderstorms and rain squalls are of frequent occurrence in the interior of Ceylon and sometimes extend to the neighbouring sea area. Weather is occasionally disturbed in the south and southeast of the Bay, and is also occasionally showery and squally in the south of the Andaman sea and between the Nicobars and Sumatra, more especially in the last fortnight of the month.

The disturbed conditions in these regions develop into storms, on the average once in three or four years. Some of the storms are severe. They generally move in a northerly to northeasterly direction towards the Arakan and Pegu coasts.

May.—The pressure conditions in the Bay change considerably in this month and the first fortnight of June. Pressure decreases steadily and considerably in the north of the Bay and increases slightly in the south of the Bay. The mean difference of pressure between the head of the Bay and the extreme southeast is about ·16 inch, giving a mean gradient of 1/4. Gradients are steepest in the northwest of the Bay where they average about 1, and decrease to about 1/6 in the south of the Bay. The mean winds of the month are directly related to the pressure gradients, ranging from westsouthwest in the extreme south of the Bay to southwest in the centre and north. Winds are strongest in the northwest and centre of the Bay where, on the mean of the month, they range between 3·5 and 4·0. They range between 3·5 and 2·5 in the extreme south of the Bay, and are feeblest between Lat. 0° and Lat. 4° N. and Long. 88° E. and Long. 100° E. The changes in the winds which occur during the month are important, and are due to the extension northwards of the westerly winds which commence in the south of the Bay in April, and in the extension southwards of the strong southwest winds prevailing in the north and northwest of the Bay. There is a marked tendency to the occasional occurrence of light variable airs and calms in the centre of the Bay between these two wind systems, and for cyclonic storms (other conditions being favourable) to originate in this central area of calms and light variable winds. As the conditions also sometimes favour the slow and prolonged development of these disturbances, they occasionally intensify into cyclones with calm area and hurricane winds. They are sometimes as intense and violent as the most severe cyclones of the October transition period, although as a rule they are usually of small extent. From the conditions prevailing at their inception they almost invariably form in the centre of the Bay, or in the Andaman Sea. They advance usually in a northerly direction and recurve northeastwards to the Chittagong and Arakan coasts. If they form near the Coromandel coast, they advance westwards to that coast or northwards to the Circars or Orissa coasts.

The mean temperature of the air in the month of May in the Bay is practically identical with that obtaining in April, averaging 84°. It is very uniform over the whole of the Bay (except of course in the immediate neighbourhood of the west coast). The temperature of the surface water ranges betwen 84° and 86°, and is on the whole greatest in the centre of the Bay, *i.e.*, in the area where calms and light variable airs are of most frequent occurrence.

The weather in the Bay is much more frequently disturbed in May than in April. In the south of the Bay weather is very changeable, intervals of fine weather with lightish westerly winds and moderate cloud alternating with periods of much cloud, squally weather, and heavy rain. In the south of the Andaman Sea near the Mergui Archipelago, weather is frequently squally in the beginning of May with much thunder and lightning. In the latter half of the month weather becomes more unsettled, and very squally weather with heavy rain frequently prevails for days together.

In the centre of the Bay weather is usually fine with light, unsteady winds and much cloud, and with occasionally very hot sultry weather. It is usually during such

periods of hot and sultry weather, that cyclonic storms form in the belt of light winds and give rise to very stormy weather over the greater part of the Bay.

Weather in the north of the Bay is chiefly dependent upon the conditions in northeast India. As a rule, southwesterly winds prevail, the strength of which depends upon the intensity of the temperature and other conditions in Bengal, Bihar, and Chota Nagpur. These winds vary in intensity considerably throughout the day. At Saugor Island and False Point they are usually strongest about 2 P.M. or 3 P.M. Nor'westers occasionally come down from the land during brief periods of unsettled weather in Bengal (usually lasting about three days). As in April these disturbances do not advance more than 80 or 100 miles seawards from land.

Occasionally very stormy weather due to the formation of cyclonic storms or cyclones prevails in the part of the Bay over which the storms advance from their place of generation to the land, and strong winds and hurricane winds may hence be experienced.

June.—The month of June may be divided into two periods, the first usually lasting until about the 7th and the second during the remainder of the month. During the first period the weather conditions are identical with those obtaining in the second half of May. Winds are from southwest to westsouthwest over the whole area and are strong in the north of the Bay, and moderate to strong in the south of the Bay, and light to moderate and unsteady in the centre of the Bay. A rapid change occurs usually in the second week of the month, practically almost simultaneous with the commencement or burst of the monsoon on the west coast. The change on the Bombay coast is so large and striking that any one can fix the day of its occurrence. Before the change, hot, sultry, dry weather with partially clouded, skies, and somewhat unsteady winds (the chief variation being that of the land and sea breezes) are the characteristic features on the Bombay coast. The change is usually ushered in by a very severe and prolonged thunderstorm and is followed by coolish but very damp weather, heavily clouded skies, frequent heavy rain, and steady, moderate to strong winds. There is no large shift in the wind direction but the character of the winds and accompanying weather completely change.

An examination of the data furnished for many years by vessels entering the ports of Bombay and Calcutta shows most clearly the nature of the change. Previous to the change the air movements in the Indian Ocean and the Indian seas are distinct and separate. In the equatorial belt between these two areas light, variable winds and calms with much cloud and rain obtain previous to the change. These winds and weather in the equatorial belt are due to the continuation of the southeast trade winds as a vertical or ascensional movement and not as a horizontal movement over that area.

In consequence of a gradual change of pressure conditions over the whole area, the nature of which would require more explanation than can be given here, the horizontal air movement of the southeast trades bursts across the equatorial belt (over which the ascensional movement hence almost entirely ceases) and is continued northward over the Indian seas. The air movement of the southeast trades is much vaster and deeper than that of the previous local air movement in the Indian seas. This rapid advance of the air movement of the southeast trades into the Indian seas hence changes very considerably the air movement in the Bay of Bengal. It replaces the local unsteady and shallow air movement by a general large and deep current, which brings up moisture from a sea area of upwards of ten times the extent of the Indian seas. There is hence a very large and radical change in the character of the winds and weather in the Bay in the month of June. It is then that what should be called the southwest monsoon proper is really initiated and from which it dates.

The change which occurs in the Bay of Bengal early in June has been fully explained above. The winds and weather in the Bay antecedent to the change are similar to those of the last fortnight in May, the chief features being moderate to strong southwest winds in the north of the Bay, unsteady and somewhat variable winds with occasional periods of calms and light airs in the centre of the Bay, and moderate westsouthwest winds in the south. Weather is showery and squally in the south and southeast, fine but hot and sultry in the centre, and fine with strong winds and occasional thundersqualls or nor'westers in the north of the Bay near the Orissa, Bengal and Arakan coasts. The advance of the moist strong air current from the southeast trades up the Bay can be easily traced by the changes it produces. The

advance is accompanied with much irregular disturbance in the south of the Bay, severe squalls with very heavy rain being the chief and most prominent feature. The irregular disturbance usually concentrates into a cyclonic storm when the advance is passing over the centre or north of the Bay. These storms generally advance westnorthwestwards across northern India and carry with them the southwest humid winds, which give a heavy downpour of rain over the storm belt, the first burst of the rains. Strong winds from the southwest generally prevail during the remainder of the month. As small cyclonic storms form in rapid succession at the head of the Bay during the rains or southwest monsoon, unsettled weather with strong winds, squalls and rain usually obtains at the head of the Bay, and strong and fairly steady southwest winds in the centre and south of the Bay during the second half of the month.

The average difference of pressure in June between the equatorial belt and the head of the Bay (a distance of 20° of latitude) is ·30″, corresponding to a mean gradient of §.

Skies are always more or less heavily clouded and the air very damp during the day. Showers and rain squalls are of occasional to frequent occurrence in all parts of the Bay, but more especially near the Arakan and Bengal coasts, the south Ceylon coast, and some parts of the Coromandel coast. Temperature falls slightly with the establishment of the southwest monsoon and averages about 82° for the Bay area. The mean temperature of the surface water also falls and ranges between 82° to 84°.

July.—The southwest monsoon conditions established in June over the Bay generally hold steadily through July and August. The strength of the air movement varies slightly in a slowly oscillatory manner, periods of strong winds alternating with periods of feebler winds. In the periods of strong winds there is much indraught from the Bay into northern India and more or less heavy and frequent rain falls in Bengal and the Gangetic plain. These periods of strong winds and heavy rain vary considerably in duration, depending upon conditions in the interior of India and also upon the general strength of the monsoon currents. Each such period is followed by a period of diminishing winds and decreasing rainfall. This change commences in the Gangetic plain and extends eastwards to Bengal and southwards over the north of the Bay. It is usually terminated by the formation in the north of the Bay of a shallow cyclonic storm, which as a rule marches northwestward and is followed by a burst of strong monsoon winds and heavy general rain. The chief features of the weather in the Bay during the month are (1st) the variations in the strength of the monsoon currents which are feebly marked in the south of the Bay but very marked in the north, and (2nd) the succession of cyclonic storms which form in the north of the Bay during the month. The average number of these storms is about three.

The mean range of pressure between the northwest angle of the Bay and the south of the Bay is, as in June, about ·30″ and hence the mean gradient is about §. Winds are, on the average, from southwest over the whole Bay except in the extreme south where the mean wind direction is from westsouthwest. Winds range between 2 and 5 in force on the mean of the month and are strongest in the centre of the Bay.

The temperature conditions are practically identical with those of June.

Weather in the south and centre of the Bay is generally fine with strong winds and much cloud, but is occasionally interrupted by rain squalls. It is much more variable in the north of the Bay, where it ranges between fine weather with lightly clouded skies and stormy weather with severe westerly squalls to hurricane winds near the centres and in the south and east quadrants of the more violent cyclonic storms of the month.

August.—The weather conditions in the Bay are practically identical with those of the preceding month (July). Southwest monsoon winds hold with comparative steadiness over the Bay and continue to pour a vast quantity of aqueous vapour into Burma and northeast India which hence receive frequent heavy rain. Pressure is unchanged in the south of the Bay, but tends on the mean of the month to increase slightly in the north of the Bay, and the average range or difference of pressure between the head and the south of the Bay is about ·25″, giving mean gradients of about 5/16. Gradients are very slightly steeper in the north and centre of the Bay than in the south or at the entrance of the Bay.

Winds average 3·7 in force both at the entrance and in the north of the Bay. Over nearly the whole of the centre of the Bay except near the coasts they range

between 4·0 and 5·5, and are strongest to the north and west of the Andamans. The mean strength of the winds in the north of the Bay is less than in the centre in consequence of the more frequent occurrence of moderate to light winds. The temperature of the air is slightly higher than 80° over the whole area on the mean of the month and is about 2° to 3° lower than the temperature of the surface water which ranges between 82° and 83° over the whole area except over a part of the entrance where it averages 84°.

Winds are somewhat variable over the extreme south of the Bay, and are on the mean of the month from westsouthwest. Over the remainder of the Bay, except in the northeast angle, they blow with remarkable steadiness from the southwest. In the northeast angle of the Bay they chiefly blow from southerly or southeasterly directions.

Skies are more or less clouded over the whole Bay area during the month. Isolated rain squalls (that is, squalls not associated with cyclonic storms) are of occasional occurrence in all parts of the Bay, but more especially off the Burma and south Ceylon coasts, and some parts of the Coromandel coast.

The strength of the southwest monsoon winds or air currents varies considerably during the month. As in July, periods of very strong winds in the Bay coincide with periods of heavy rainfall in northern India. In the intervals between the periods of heavy rains in northern India and of strong winds in the Bay, winds fall off at the head of the Bay ; and fine weather sets in with a decreasing sea. These periods are usually terminated by the formation of a cyclonic storm (in the northwest of the Bay to the north of Lat. 16° N.). On an average about three such storms form in August. They generally advance in a westnorthwest track across the Orissa coast. As a rule, the winds near the centre and to the south do not exceed 8 to 9 in force (a moderate to strong gale) but occasionally winds of force 10 to 11, approaching hurricane force, are experienced. Weather is very squally and stormy during the formation and advance of these depressions in the north of the Bay, and the southwest monsoon winds in the centre of the Bay are considerably intensified, blowing with a force ranging between 5 and 7.

September.—The conditions in this month are very similar to those of July and August. Pressure continues on the mean of the month unchanged in the south of the Bay but rises slowly in the north of the Bay. The average pressure difference between the head and the south of the Bay is about ·20″ as compared with ·25″ in August and ·30″ in July. The mean pressure gradient over the Bay in September is ⅔ as compared with ⅘ in July. The gradients are nearly uniform in amount over the whole Bay. Hence the mean strength of the winds in the Bay is slightly less than for August and there is less variation in their intensity. Winds average 4·0 in force at the entrance to the Bay and 3·0 in the north of the Bay (due to occasional intervals of light unsteady northerly winds). In the centre of the Bay they range between 4·0 and 5·0 and are apparently strongest in the centre of the Bay to the west and southwest of the Andamans. Winds are somewhat less steady and more variable in direction in September than in August and July, more especially in the northwest of the Bay. They blow chiefly from westsouthwest in the south of the Bay, from southwest in the centre and west of the Bay, and from south or south by west at the head and in the northeast of the Bay.

There is practically no change in the temperature of the air over the Bay during the month. The mean of the month is about 79° in the Andaman sea and 80° to 82° in the Bay, temperature being slightly higher near the Coromandel Coast than elsewhere.

Skies are generally more or less clouded over the greater part of the Bay during the month. Isolated rain squalls (*i.e.*, squalls not associated with cyclonic storms) are of occasional occurrence in all parts of the Bay and are most frequent off the Arakan and Tenasserim coasts and the south Ceylon coast. The strength of the air movement varies from day to day in an irregular manner, periods of strong winds alternating with intervals of lighter winds. The intervals of lighter winds and fine weather are more prolonged than in July and August, and hence the periods of heavy rain and strong winds are shorter and less marked than in the previous two months.

The intervals of fine weather are usually terminated by the formation of cyclonic storms. They occasionally form further south than in the preceding two months, and also under exceptional circumstances may develop into cyclones of great intensity.

comparable with the May and October cyclones. Hence stormy cyclonic weather is of occasional occurrence in the north and centre of the Bay. As a rule, from two to three storms form in the Bay during the month. Winds generally do not exceed force 8 and 9 near and to the south of the centre, but hurricane winds of force 12 have been experienced.

October.—The last week of September and the month of October witness a large change in the pressure and other metecrological conditions in India. Pressure increases rapidly in northwest India and moderately in northeast India and the north of the Peninsula and falls slightly in the south of the Bay. The effect of these changes is to give almost uniform pressure over the whole of India with a tendency to slightly lower pressure in the centre of the Bay than elsewhere. These important changes accompany the withdrawal of the moist southwest monsoon currents from northern and central India. This change commences in upper India (*i.e.*, the Punjab, Sind, and Rajputana) where the rains usually cease in the third or fourth week of September when light, variable winds with clear skies and dry weather set in. Somewhat later, in the beginning of October, the rains usually cease in the Gangetic plain and central India and fine, dry weather sets in, extending southwards and eastwards from the Punjab. Showery weather continues for some days longer in northeast India and the Central Provinces, but in the third week of the month the moist winds usually withdraw from these provinces. Damp, muggy weather with very light unsteady winds prevails in these two areas during the remainder of the month. The change described above is hence comparatively slow and gradual, and each stage of the change is marked by a corresponding change in the pressure conditions. The final result in the third week of October is to give almost uniform pressure over the Bay with a very slight tendency to low pressure in the centre of the Bay. These pressure conditions accompany the prevalence of very light airs and calms over the centre of the Bay. Westerly winds continue over the south and southeast of the Bay, whilst northeast winds tend to set in over the northwest angle of the Bay. The continuance of the damp southwesterly to westerly winds over a part of the Bay forms one of the conditions necessary for the formation of cyclonic storms or cyclones and the uniformity of the pressure conditions favours their slow growth into large and intense cyclones. The weather in the Bay during the month is hence more variable and treacherous than in any other month of the year. The finest weather frequently prevails for considerable periods in the north and centre of the Bay. Occasionally, however, the largest and fiercest cyclones form and march across it, giving hurricane winds and a dangerous sea.

Winds are exceedingly variable in the north and centre of the Bay and show no predominant direction. They usually range between 0 and 2 in force during the fine weather of the month. To the south of Lat. 12° N. winds are chiefly from southwest or westsouthwest and average 3 in force over the south of the Bay and 4 to the south of Ceylon.

The mean temperature of the air in October in the Bay is practically the same as in September. It averages about 79° in the Andaman Sea and between 80° and 82° in the Bay. The temperature of the surface water is slightly greater (about 1°) in the north of the Bay averaging 81°.

The preceding remarks indicate the general character of the weather in the Bay during the month.

During the greater part of the month weather is fine with light winds and clear skies or passing clouds in the north of the Bay. Occasionally weather is disturbed or stormy due to the influence or passage of a cyclonic storm which has formed in the centre of the Bay. Weather is hence very variable during the month over the north of the Bay. There is a marked tendency to the occurrence of very light airs and calms with cloudy, showery weather, with prolonged intervals of fine, clear weather in the centre and north of the Bay. As a rule from one to two storms form in this area during the month and these storms occasionally give cyclonic weather of the most violent kind. Over the south of the Bay the southwest winds of the southwest monsoon continue to blow with more or less regularity. They are usually feeble (not exceeding force 3) when fine weather prevails, but invariably intensify when squally or stormy weather prevails in the centre of the Bay. Weather is then frequently squally in the south of the Bay with heavy cloud and a high swell.

November.—The most important feature of the month is the increasing weakness of the southwest monsoon current and winds over the south of the Bay. Pressure continues to rise in the north and centre of the Bay, and on the mean of the month pressure is about a twentieth of an inch higher in the north than in the centre of the Bay. Pressure is usually lowest in a belt stretching across from the Coromandel and Ceylon coasts to the Nicobars. Northeast winds, light to moderate in force, prevail fairly steadily throughout the month in the north and greater part of the centre of the Bay. Light variable unsteady winds, as a rule, obtain in the area of lowest pressure between the Andaman and the Ceylon and south Coromandel coasts, whilst over the entrance to the Bay moderate westerly winds generally prevail. The wind force in the north and centre of the Bay ranges between 3 and 4, and in the central area of lowest pressure between 2·5 and 3·2. Over the entrance to the Bay they average 3·0 in force. Fine weather with clear skies generally prevails over the northern half of the Bay. Weather is frequently showery to squally in the south of the Bay where the damp westerly winds of the retreating southwest monsoon still blow. Cyclonic storms, one to two in a month, tend to form in the belt of variable winds and hence considerably further south than in October. The conditions are less favourable for their full and slow development, and hence they do not attain the intensity or extent of the most severe October cyclones. They, however, invariably give very stormy weather in the southwest and centre of the Bay, and winds are occasionally of hurricane force near their centres.

Temperature now falls rather rapidly in the north of the Bay and the mean temperature of the air during the month ranges between 75° in the north of the Bay and 80° near the Ceylon coast.

December.—The month usually witnesses the complete and final withdrawal of the southwest monsoon currents from the south of the Bay. The pressure changes are the continuation of those of the previous month. Pressure continues to increase in the centre and north of the Bay, and on the mean of the month there is a pressure difference of about ·15″ between the head of the Bay and the extreme south, corresponding to the gradient of 3/16 for northerly winds. The area of lowest pressure shifts southwards and passes out of the Bay into the equatorial belt usually in the third or fourth week of the month. Steady northeasterly winds prevail during the month over the north and centre of the Bay. These winds are comparatively feeble at the head of the Bay (averaging 2·5 in force), but increase in strength southwards to about Lat. 12° No. off the Coromandel coast, where they average 4·0 in force. Winds are light and very unsteady between the equator and Lat. 6° N., but show a marked tendency to northerly directions.

Weather is usually cloudy, with occasional showers or squalls, in the extreme south of the Bay. Occasionally but much less frequently than in November, cyclonic storms form in the area of low pressure in the south of the Bay. Sometimes these storms are imperfectly developed as cyclonic circulations, but are remarkable for the heavy rain and squally weather they give. They almost invariably cross the south Coromandel coast, or in the case of the imperfectly developed storms, the east Ceylon coast. They give squally weather with heavy rain, but the winds as a rule do not rise above force 8 to 9 near their centres.

Temperature falls rapidly during the month in the north of the Bay. It ranges between a mean of 69° at the head of the Bay and 75° in the 16th parallel of latitude, and between 75° and 80° between the 16th parallel and the entrance to the Bay.

CHAPTER III.—PHENOMENA OF CYCLONIC STORMS.

Preliminary Remarks on Cyclonic Storms.—In the present chapter we deal with the chief object of the book, *viz.*, the more important features and peculiarities of cyclonic storms in the Bay of Bengal, and more especially those features which can be observed by a sailor and employed as indications to determine the probable character, position, and track of any cyclonic storm he may encounter when navigating that sea.

It has been explained in a preceding chapter what is meant by a barometric depression and what by a cyclonic circulation. We have also stated that in an area of barometric depression (that is, an area in which the barometer stands lower than in neighbouring districts and gradually rises outward from some central position in all directions), the air moves invariably in a particular direction and manner round this central position, and that such an air motion is technically called a cyclonic circulation. Frequently, the air motion in such a circulation is feeble and winds light. There is, however, under favourable conditions in the Bay of Bengal, a marked tendency for a cyclonic circulation when established to become stronger and more vigorous ; when this is the case, the cyclonic circulation may gradually develop into a cyclonic storm. *All large storms in the Bay of Bengal are cyclonic circulations : all cyclonic storms are of more or less gradual growth and commence as feeble circulations.* Hence cyclonic circulations in the Bay are of very varying strength or intensity, as well as of magnitude. It is of course not possible to draw hard-and-fast lines in such matters. Hence cyclonic circulations and cyclonic storms differ in two elements—extent and intensity. In the area covered by a cyclonic storm, the winds increase in force from the outer limit to the centre or the central calm area (if there be one) : over a portion of this area nearest the centre, winds of force 7 and 8 upwards to 12 may prevail. This inner area forms the storm area of strong to dangerous winds. The size, or greatest width, of this area gives a rough measure of the magnitude or extent of the storm.

The intensity is best and most easily measured by the depth to which the barometer at the centre falls. The simplest standard of reference is the ordinary or normal height of the barometer at the time. The difference below this and the actual height of the barometer at the centre gives a rough practical measure of the intensity of the storm.

The intensity of cyclonic storms appears to be, to a very considerable extent, independent of their magnitude. Thus, it is not only possible to have a storm of considerable extent but of very feeble intensity, but it is also possible to have a storm of small extent, and of great and even extraordinary intensity. The most intense storm in the Bay of Bengal on record is the False Point cyclone of September 1885, in which the barometer at the centre was approximately 2½ inches lower than usual at that period of the year. The largest storm, as well as the most intense storm in the Bay was the Backergunge cyclone of October 1876.

The storm area in the case of the largest and most intense cyclones may be divided into two portions : an outer and an inner storm area. In the outer storm area, the barometer falls slowly and to a moderate extent, and the winds are of force ranging from 6 to 9 or 10, the strongest winds being experienced in the squalls. In the inner storm area the barometer falls with excessive rapidity from the outer edge to the central area (which is in the Bay of Bengal an area of calms). The baric gradients are hence excessively steep, the winds of hurricane force, the shifts of wind rapid, and the sea very high, confused, and dangerous. The most remarkable feature of this inner storm area is a small central area, usually known as the calm centre, or bull's eye of the storm, in which there is little or no wind and cloud, the sun or stars usually visible through a thin veil of mist, and the sea pyramidal and boiling like a cauldron.

The reader should hence remember that in the most vigorous cyclones of the Bay of Bengal the storm forms only a portion (the inner portion) of a cyclonic circulation. In the outer portion of the cyclonic circulation, the winds are governed by the indraught to the storm area, but are of moderate force, and not of sufficient intensity to be considered as stormy winds. The inner portion of such a cyclonic circulation includes :—

(1) The outer storm area in which winds of force 6 to 9 prevail.

(2) The inner storm area in which winds of force 10 to 12 prevail.
(3) The calm central area.
The ratios of the magnitude of these differ very greatly in different storms.

By far the larger proportion of cyclonic storms which occur in the Bay are of small extent and moderate intensity. In these storms there is no calm centre, and rarely an inner area of hurricane winds. The weather, sea, and winds in these storms are such as occur in the outer storm area of the severe and dangerous cyclones described in the preceding paragraph. Cyclonic storms of sufficient extent and intensity to be dangerous occur in the Bay only during the period that southwest winds are blowing more or less steadily over the entrance and south of the Bay—that is, from the beginning or middle of April to the end of December. This period will for convenience be called the "cyclone season". Cyclonic storms may occur in the Bay at any time during this period. The character of the storms varies to some extent during this period, being dependent on the general weather conditions prevailing at the time of their origin.

During the months of January and February, steady and moderate northeast winds and fine clear weather usually prevail in the Bay. These northeast winds of the northeast monsoon are analogous to the corresponding winds of the northeast trades In the beginning of March, with the rapid increase of temperature in northern and central India, local sea-winds commence at the head of the Bay and strengthen. These winds back down the Bay to some extent in April. During this period of gradual change from the prevalence of dry land winds in the interior to the setting in of the humid winds of the southwest monsoon period (which may be termed the May transition period) the northeast winds in the Bay become feebler and are replaced by light, unsteady, variable winds in the centre of the Bay in April and first half of May. This continues until the latter part of May or beginning of June when, after one or two preliminary feeble efforts, the true southwest winds of the southwest monsoon advance rapidly up the Bay, and shortly afterwards penetrate into Burma, Bengal, and gradually into upper India.

This change introduces the southwest monsoon winds and rains proper into India, which last until about the middle or end of September. After this the rain-giving winds retreat and tend to back down the Gangetic plain and the Bay. The retreat of these winds in the Bay, unlike their advance, is a very slow process and continues until about the end of December. In consequence of the peculiar conditions then prevailing in the Bay, the southwest winds still blowing over the south of the Bay, curve through south, southeast and east, and thus reach the Coromandel coast as northeast damp winds, and give for a period of about two months occasional moderate to heavy rainfall to southern India. The commencement of these rains in October in southern India is usually termed the beginning of the northeast monsoon, but the rains ought really to be thought of and called "late or retreating southwest monsoon rains". This period of slow change from the prevalence of the southwest monsoon over the whole of India to its final retreat from the Bay is, for convenience, called the October transition period. The division of the year described above is hence as follows :—

(a) Northeast monsoon period, from January to March, characterized by fine weather and absence of cyclonic storms in the Bay.

(b) May transition period, extending from the beginning of April to the beginning of June, characterized by the extension of southwest winds in the north and south of Bay, and terminated by the general advance and establishment of the southwest monsoon.

(c) Southwest monsoon period, from June to September, or period of general rain in India with the prevalence of steady southwest winds over the whole of the Bay, the Arabian Sea, and most parts of India.

(d) October transition period from October to December, marked by decay and retreat of the southwest current in the Bay, and terminated by its final disappearance.

The experience of many years has shown that during the southwest monsoon period proper, *i.e.*, from June to September there is a rapid succession of cyclonic storms of moderate extent and small intensity. These are the storms of the rains proper. In many cases they form quite close to the coast of the Sunderbuns or

occasionally in south Bengal, and their only prominent feature which comes to the notice of sailors is the very strong westerly winds which blow in their southern quadrant near the head of the Bay. Hence they are sometimes described as westerly gales, but it should be remembered that they are in all respects cyclonic storms.

During the May and October transition periods, storms on the whole occur less frequently than during the rains proper. The majority of the storms of these two periods are of moderate extent and intensity, but occasionally they develop into storms of great extent or intensity. A rough calculation, based on experience, shows that about one out of three cyclonic storms which occur during these periods, is a fierce and dangerous cyclone with an inner storm area of hurricane winds and a calm centre.

There is hence a very marked distinction between the smaller cyclonic storms, which are of frequent occurrence during the whole cyclone season, and more especially during the rains proper, and the intense cyclones which are of very occasional occurrence and appear only during the transition periods.

It has already been pointed out that cyclonic storms form gradually, and if conditions are favourable increase in intensity until they become fierce and dangerous storms.

The order of growth of a cyclone is—

(1) Squally weather, with irregular winds.

(2) Squally weather, with cyclonic circulation of moderate intensity.

(3) Intensification of the cyclonic circulation, commencement of hurricane winds near the centre, and the development of calm centre.

Character of the weather and sea disturbance in the smaller storms of the rains proper.—The character of the smaller cyclonic storms of the rains has been to a certain extent already described. They may occur at any time between the beginning or middle of June and the middle or end of September. The barometer at the centre is rarely more than two or three-tenths of an inch below the normal pressure of the period. Judging from the experience of the past twenty years they very rarely if ever, have a well-marked calm centre. The winds to the north, northwest and west of the centre of wind convergence are comparatively feeble. For example, in the storm of July 1883, when hurricane winds of force 11 and 12 were blowing at the Sandheads, over which the centre was slowly drifting, the force of the northerly winds at Saugor Island, 50 miles to the north, at the same time, was only 3 to 4. In these small storms strong cyclonic winds are only experienced in the great majority of cases in the south and east quadrants. Hence the cyclonic nature of these storms was for many years overlooked and they were regarded simply as westerly gales. This was of course due to the fact that they formed near the head of the Bay, and hence, the only marked feature of the storm which came under the notice of sailors was the strong westerly and southwesterly winds which prevailed in the centre and north of the Bay during the storm and for some time after its passage inland. They are, notwithstanding, true cyclonic storms with a centre of indraught, exactly as is the case in the cyclones of October and November, and the same rules for the determination of the centre and line of march apply as in the case of other cyclonic storms in the Bay. As the barometric depression at the centre is small and the storms are of small extent, they are never accompanied by storm waves, such as frequently cause in the case of the October cyclones so much destruction of property and loss of life in the low-lying lands at the head of the Bay.

The chief indication of the formation of one of these storms on the Orissa and southwest Bengal coasts is the suspension of the ordinary southwest monsoon winds and the setting in of northeast or east winds, and of comparatively fine and dry weather in the midst of the rainy season.

If a vessel leaves the port of Calcutta and proceeds down the river during the months of June, July, August or September, while these unusual conditions prevail, *viz.*, light northeast or variable winds with fine, bright, sultry and comparatively dry weather, the sailor may be almost certain that there is dirty weather at the head of the Bay. It may be no more than squally weather, but it may be a severe storm of the rains. It should, however, be remembered that as these storms are small, they may give rise to more rapid shifts of wind than the larger storms of the October

period. The wind and sea in the southern and eastern quadrants are frequently almost as dangerous and trying as in the larger cyclones of the October period.

Character of winds to the north and west of cyclonic storms in the Bay of Bengal during storms of the rains proper.—It has been pointed out more than once that the most important feature in cyclonic storms is the strong southwest moist winds which feed into them. Hence it becomes important to know the chief features of the southwest monsoon winds, as it is probable that cyclones may in part at least depend upon changes in that current. The observations of recent years, both on land and at sea, prove that the southwest monsoon is much more variable than was formerly supposed. It is not a steady air-current like the southeast trades in the Indian or Pacific Ocean. It appears, on the contrary, to go through a series of pulsations. During the first part of each of these periods it advances in force into the interior of India and gives general rain for some time. Afterwards it appears to weaken and backs down the Gangetic Plain, and the strong rain-giving winds in northern India are replaced for a short time by light unsteady winds. This is followed by another advance of monsoon rain-giving winds, and so on throughout the whole monsoon season. These variations of strength and alterations of advance and withdrawal form the most conspicuous and one of the most important features of the southwest monsoon in northern India.

It is found that almost without exception during the rains proper, all the cyclonic storms that are generated during the period between the 15th of June and 15th of September form in the intervals between the partial retreats and advances of the monsoon current. They hence appear to commence to form in front of an advancing rush of moist winds, and, as they march across the coast into the interior, they carry the damp winds and rain with them. They are hence one cause of the very unequal way in which the rains are frequently distributed during the southwest monsoon in northern India, as these storms draw the rain away from other districts to distribute it in large amounts over the narrow belt along which they advance. These storms of the rains, as has been pointed out, are almost invariably of small intensity, as measured by the barometric depression, and generally give moderate cyclonic winds, although occasionally (in about one storm out of five or six) they are attended with winds or squalls of hurricane force near the centre at sea.

These facts will enable the character of the winds in the west quadrant of the cyclonic storms of the rains proper to be understood. Before they commence to form, and whilst they are forming, the regular southerly winds of the season are, to a large extent, suspended in Bengal and at the head of the Bay. Light unsteady winds prevail, and the weather is sultry and oppressive. A rush of strong monsoon winds commences in the centre of the Bay, drawn or pressed forward by some force. Squalls begin to occur and increase in frequency and intensity, and a small whirl (perhaps) begins to form. If this be the case, the whirl thus started, after some time varying very considerably in length according to circumstances, advances landwards and carries heavy rain with it to the districts over which it passes.

It is hence the winds in the southern and eastern quadrants which bring up the energy that starts and maintains the storm. They are, moreover, the normal winds of the season, intensified locally by the cyclonic indraught. The winds in the western quadrant are abnormal winds, with little or no energy, dragged into the storm.

Character of winds to the north and west of cyclonic storms of the transition periods.—The circumstances are different during the formation of storms in the May and October transition periods. During these two periods the southwest monsoon is not in full possession of the Bay. In the first or May transition period the southwest monsoon has not advanced up the Bay, and hot-weather conditions prevail in Bengal and at the head of the Bay. In the latter, or October transition period, it is retreating down the Bay and the (so-called) northeast monsoon is setting in on the Coromandel coast. The character of the winds in these two cases differs slightly at the head of the Bay immediately before the advent of a cyclone. It may be premised that these cyclones are occasionally very extensive and fierce storms. In the inner central or storm area the winds are governed by the cyclone only, and show that rotatory motion, combined with indraught to the centre, which is the essential feature of rapid cyclonic air motion. The winds are, however, in all cases influenced more or less to a very considerable distance away from the inner storm area. If the cyclonic

storm be at a considerable distance from the place of observation and the wind that is slightly influenced by its action or indraught be the normal wind of the season, its only effect may be to strengthen that wind, which will hence be apparently normal in character, but steadier and stronger than usual. Hence it may happen that a wind from such a direction, which is usually a fair weather wind, may under these conditions blow directly into a cyclonic storm. This is especially the case in the cyclones of the months of October and November at the head of the Bay.

If a cyclonic whirl forms at that time in the Bay, it is usually generated in the centre of the Bay, and advances in some direction between northeast and west, the average direction being northwest. The tendency of such a whirl is to produce northeast winds in the northwest quadrant or in the northwest of the Bay, and also to cause them to shift round to east if the cyclone takes a northwest or west track.

Hence the effect of the distant cyclone is generally (*i.e.*, in at least two cases out of three) to strengthen the northeast winds and to give them a tendency to veer to east, and also to increase their steadiness, and so long as the centre is at a considerable distance, the weather is fine and bright, and atmosphere frequently unusually clear. Hence it may be that when these winds are apparently most favourable for a ship outward bound from the Hooghly and the weather also even finer looking than usual, they are really feeding into a cyclonic storm farther south.

They are in this case exceptionally treacherous and dangerous as they may carry a ship southwards in front of an advancing cyclone, where she would not have sufficient sea-room to be able to manœuvre and escape from the inner storm area.

It will thus be seen that northeast winds at the head of the Bay, and more especially in the northwest angle of the Bay, during the months of October and November, may indicate entirely different weather conditions. They may be—

1*st.*—Merely the normal winds of the season and accompany fine clear weather in the north of the Bay and in Bengal, and either fine weather or squally weather with rain in the south of the Bay, more especially in the neighbourhood of the Coromandel coast. In this case they are generally light, and shift through two or three points during the day in consequence of the heating of the land by day and its cooling by night.

2*nd.*—If these northeast winds are stronger and steadier than usual this may be due to one of the two following causes :—

(a) A stronger northeast monsoon than usual on the Coromandel coast and in southern India. In this case weather is usually showery with much rain and strong winds in the Carnatic, and squally in the Bay of Bengal off the Coromandel coast. During such a period pressure is frequently unusually high in northern India, and fine, clear weather with moderate west or northwest winds prevails in Bengal and the Gangetic plain.

(b) The formation and existence of a cyclonic storm in the centre or south of the Bay. In this case the weather is generally unusually fine and the air remarkably clear.

General character of barometric changes during storms in the Bay of Bengal—Small barometric changes are the rule in the Bay of Bengal, and large changes are, not only the exception, but are very rare indeed ; the small changes which accompany stormy weather in the Bay take place usually at a slower rate than the regular motions. For a fall of two-tenths of an inch in 24 hours at a given place is of very occasional and rare occurrence, whilst the total fall and rise due to the diurnal tides on the average exceeds a tenth of an inch in each of the six-hourly intervals between maximum and minimum. Hence it is that they are so rarely obscured or obliterated by the changes due to cyclonic storms. Consequently, due allowance must be first made for these regular changes, if we wish to ascertain what the irregular changes are—which are the only part that we are concerned with in determining the probable weather.

Banks of clouds.—When a cyclonic storm has formed, large masses of air are carried rapidly upwards in the body of the cyclone or over a considerable portion of the inner storm area. The aqueous vapour with which it is laden is in part condensed rapidly. Huge nimbus, pallium or rain clouds are formed from which rain is poured down in torrents. Hence, over the central area there is a permanent dense black mass

of clouds which moves with, and is a part of, the cyclone. The permanent state is, of course, one of appearance or passage only. The air, as it rises up and passes through the cloud-charged space, has a portion of its aqueous vapour condensed, and thus contributes or adds to the mass of the cloud, whilst at the same time the cloud is continually losing a portion of its mass by the rainfall. The cloudmass is hence in a state of constant growth and decay. Its appearance at a distance is that of a huge bank of clouds resting on the horizon, which retains its form unchanged for hours. It is usually most conspicuous about sunrise and sunset. If a ship should travel at about the same rate as the cyclone, this huge bank of clouds may be observed for several days in succession. As also much electric action goes on in the body of a cyclone, more especially in these quadrants (*viz.*, the eastern and northern), where the air is chiefly being carried upwards. At night the lightning is visible at immense distances. If, as is frequently the case, it may be seen by reflection from higher clouds, calculation indicates that the reflection of the lightning might be seen in this way at distances of from 300 to 400 miles under very favourable circumstances, and at distances of 50 to 100 miles under ordinary circumstances, such as are likely to occur in any storm. Hence, the appearance of a dense bank of clouds on the horizon which retains its shape for hours practically unchanged, and in which (especially at night) frequent electric action or lightning is seen, is an almost certain indication of a distant cyclonic storm. The indication is even more valuable if the same appearance be observed on two or three nights in succession. It is therefore an indication of considerable importance, and is frequently the first marked sign of the distant formation and approach of a cyclonic storm.

Occurrence of squalls before and during cyclonic storms.—It should be kept carefully in view by mariners in the Bay of Bengal that the formation of a cyclonic storm is a gradual process, and that it is only when the disturbance has passed beyond the initial stages that it becomes a storm in the proper sense of the word. The formation of a large storm is due to the prolonged continuance of actions, processes and changes of the same kind as those that are occurring in the atmosphere at all times when rain is falling and strongish humid winds are blowing. Whatever the causes and origin of cyclones may be, the history of all cyclones in the Bay shows that they are invariably preceded for longer or shorter periods by unsettled squally weather, and that during this period the air over a considerable portion of the Bay is gradually given a rapid rotatory motion about a definite centre. During the preliminary period of change from slightly unsettled and threatening weather to the formation of a storm more or less dangerous to shipping, one of the most important and striking points is the increase in the number and strength of the squalls which are an invariable feature in cyclonic storms from the very earliest stages. First of all, the squalls are comparatively light and are separated by longish intervals of fine weather and light, variable or steady winds, according to the time of the year. They become more frequent and come down more fiercely and strongly with the gradual development of the storm. The area of unsettled and squally weather also extends in all directions, and usually most slowly to the north and west. If the unsettled weather advances beyond this stage (which it does not necessarily do) it is shown most clearly by the wind directions over the area of squalls. The winds always settle down into those which invariably occur over an area of barometric depression or cyclonic circulation, or, in other words, are changed into the cyclonic winds of indraught to a central area of low barometer and heavy rain. As soon as the wind directions indicate that a definite centre of wind convergence has been formed in the Bay, it is also found that the centre never remains in the same position for any considerable interval of time, but that it moves or advances in some direction between northeast and west with velocities which not only differ very considerably in different storms, but also at different stages of the same storm.

This preliminary period of unsettled squally weather may extend over several days, or may last only a few hours. It is of course impossible to determine exactly the hour at which the change from the antecedent disturbed squally weather to the cyclonic storm takes place.

Hence the chief feature of this antecedent period or first stage in the formation of cyclonic storms in the Bay of Bengal is squally weather. In those parts of the Bay where southwesterly or southerly winds are blowing, the winds are

generally strong, varying in force from 3 to 6 or 7. These winds become the winds which prevail in the southern and eastern quadrants of the cyclone, if the squally weather developes into a cyclone. In another portion of the Bay during the formation of a cyclone (always to the north or west of the area of strong southerly winds) is an area of light and variable winds (sometimes shifting in a few hours all round the compass) or of calms. But whatever the direction or character of the wind in any portion of the Bay may be, if a cyclonic storm originates and forms over it, the occurrence of occasional rain-squalls is the first indication of the commencement of disturbed atmospheric conditions, or the threatening weather which may under favourable conditions develop into a cyclonic storm. These squalls are at first of short duration and comparatively feeble, but if they increase rapidly in frequency and intensity, they are an almost certain indication of the commencement, or of the existence of a cyclonic storm, and they become more and more prominent and more frequent and severe during the birth and growth of the cyclonic storm. It should, however, be carefully noted that squalls more or less severe occur under several sets of conditions in the Bay, and it is hence desirable to discriminate between these. This is the more necessary in order that it may be fully realized that whilst *squally weather is a necessary antecedent in time to the commencement of a cyclonic storm, squally weather is not necessarily followed by a cyclonic storm.*

Squalls of brief duration, lasting from a few minutes to one or more hours, may pass over vessels navigating the Bay due to a variety of causes. They appear to occur chiefly under three different sets of circumstances, and hence may be divided into three different kinds described in the following paragraphs.

1st.—Squalls which usually originate in Bengal or Orissa near the sea coast during the hot weather months of March, April, and May.—They generally occur in the afternoon or evening after the day sea winds have been blowing across the sea coast for some hours. Many of them appear to begin over the hills in Orissa, west Bengal, and east Bengal. In all cases when they occur in south Bengal, clouds appear to gather in the north or northwest quarter, and gradually acquire the black, dense appearance and rounded mushroom-shape characteristic of thunder-clouds. The rapid and irregular motion of these clouds, the manner in which portions of the clouds appear to be torn off from the rest, the large electrical action shown by the almost continuous thunder and lightning which frequently accompany them, and the occasional occurrence of hail, and other features all indicate very considerable atmospheric disturbance, which is, however, usually confined to a very small area. The disturbance apparently gathers force for some time, and then rushes down as if from a higher altitude, giving violent winds along its path, and is attended with much thunder and lightning, and frequently with heavy rain or hail. The wind veers considerably during the passage of these squalls. As they generally come down from the northwest quarter in Bengal they are usually termed nor'westers. These squalls appear to be of comparatively brief existence and to die away even more rapidly than they are formed. If they pass from the land to sea, they are then comparatively feeble and disappear at a short distance from the sea coast. They are hence chiefly felt in the neighbourhood of the Bengal and Orissa coasts in the months of April and May. They are occasionally very violent in the River Hooghly and the mariner should hence be on his guard in these months, especially as the first rush of the winds which accompanies them is usually very sudden, and the force of the winds is sometimes very great, nearly as great as in the severest cyclones. In a nor'wester which passed over Calcutta in May 1883, the velocity of the wind, as indicated by an anemometer on the roof of the Meteorological Office, exceeded 100 miles per hour in the severest gusts of the squalls. Carriages were overturned, trees blown down, and some of the ships in the river were damaged. One steamer at least was obliged to remain a day later in port in order to repair the damages caused by the storm.

An examination of the whole of the information contained in the logs of the vessels sent in to the Meteorological Office shows that they are by no means uncommon near the Sandheads and at the entrance of the river. They are, so far as can be judged from the information in the Meteorological Office, rarely felt to the south of Lat. 20° N., and then only in the immediate neighbourhood of the Arakan and Orissa and Madras coasts. At the Sandheads they occasionally come down very fiercely and raise a very rough and nasty sea. Hence it is always advisable that mariners proceeding down the

Hooghly in the months of April and May, when they see a dense bank of clouds in the northwest quarter, such as is usually indicative of the probable approach of one of these squalls, should prepare for a severe squall. This, it has already been pointed out, is very advisable, because these squalls always come down very suddenly, and the first rush of these storms is sometimes exceedingly severe.

2nd.—Isolated squalls during the Southwest monsoon.—Whenever a moist air-current is blowing, there is always a tendency to the formation and occurrence of rain-squalls. This tendency is apparently very much increased if the moist air-current meets with any sudden obstruction, or if it advances towards another air-current which differs much in temperature, humidity or other characteristic features. Hence, in front of the advancing southwest monsoon up the Bay in the months of May and June there are always frequent rain-squalls. These squalls appear to be very frequent in the neighbourhood of Ceylon just before the southwest monsoon current enters the Bay in May.

The first advance of monsoon winds over the south and centre of the Bay apparently resembles to some extent the sudden advance of a rapidly moving fluid mass into an inert mass, and there is much irregular and whirling motion. This shows itself by the frequent occurrence of squalls. During the prevalence of the southwest monsoon the winds blow intermittently, that is strongly for some days, and then fall off in strength. Each advance is similar in character to the first great burst of the monsoon in May or June. It is a rush of strong winds over an area previously occupied by feeble winds, and is attended with more or less squally weather. Hence, squalls are of frequent occurrence over the Bay at the commencement of the monsoon, and over the north of the Bay during the whole monsoon period from May or June to October. As already pointed out, the air current which gives rise to these squalls is a damp humid current, bringing up vast quantities of aqueous vapour, and hence having a vast store of energy. If this energy be released and set free rapidly, the squally weather, which indicates slight atmospheric disturbance, may gather strength and grow into a large cyclonic storm.

The neighbourhood of the west Pegu and south Arakan coast appear to be very liable to rain-squalls during the height of the monsoon. These are evidently due to the obstructive action of the Arakan hills, which are from 1,000 to 4,000 feet in height, and which divert the direction of the monsoon current from S.W. to S. and S.E.

The neighbourhood of the Madras coast also appears to be subject to these squalls during the southwest monsoon months, July to September. The southwest monsoon winds which blow across the Bombay coast are forced up across the Western Ghats, during which they give up a considerable portion of their moisture, and thence proceed across the Deccan as comparatively dry winds. The wind directions of the Deccan stations indicate that the current advances eastward across the Peninsula, and nearly at right angles to the current up the Bay of Bengal. Its velocity is considerable, nearly as great as that of the Bay of Bengal current. Much irregular motion and action occur near the meeting ground of these two aerial currents, just as is the case where two large rivers meet when, as is well known, there is much irregular and whirling motion, accompanied by up-rushes and down-rushes of small portions of the water. Hence, during the rains proper, rain-squalls are of occasional occurrence along and near the west coast of the Bay. This action is, as might be expected, most frequent near the head of the Bay. This interference of the Bombay branch of the monsoon current undoubtedly gives rise to frequent squalls in that part of the Bay, and it is probably in part due to this that small cyclonic storms occur so frequently during the months June to September.

3rd.—Squalls during cyclonic storms.—An interesting point in connection with the occurrence of squalls in cyclonic storms and cyclones is their distribution with respect to the different quadrants of the storm. It is a point on which it is not easy to obtain very satisfactory information. An examination of the records in the Meteorological Office of the weather in the Bay of Bengal during the six years 1882-87 gives the data tabulated below.

The cyclonic area is divided into four quadrants, *viz.*, northeast, southeast, southwest and northwest, and the number of different occasions on which severe to intense

squalls were observed in each of these quadrants during cyclonic storms or cyclones in the period 1882-87 is given in the columns of the following table :—

	Number of occasions on which severe to intense squalls were noted by different vessels in cyclonic storms.				
	N. E. Quadrant.	S. E. Quadrant.	S. W. Quadrant.	N. W. Quadrant.	Total
Months of May, June, July, August, and September.	9	19	18	3	49
Months of October and November ..	18	13	12	14	57

The results are very interesting, and, although not pretending to exactness, probably give a rough approximation to the law of distribution. They show first that in the storms of the rains heavy squalls are far more frequent in the southeast and southwest quadrants than in the northeast and northwest quadrants, and that they are of rare occurrence in the northwest quadrant.

In the cyclones of October and November they occur with nearly the same frequency in all quadrants, but with a slight tendency to greater frequency in the northeast than in the other three quadrants. The table also indicates that severe to hurricane squalls occur more frequently during the two-monthly period of October and November than during the five-monthly period extending from May to September.

The eye of the storm.—One of the most remarkable features of the more severe cyclones of the tropics is the area of very light winds, or absolute calm in the centre of the storm. Over this area the torrential rain of the hurricane ceases, and the clouds frequently break away, showing blue sky, with the sun or the moon and stars. On account of its peculiar clearness this spot has received the name "the eye of the storm."

The eye of the storm is a calm area varying very largely in diameter, but rarely exceeding 15 to 20 miles in diameter, characteristic only of the most violent class of tropical cyclones. Immediately outside this central area of these cyclones the wind is indescribably furious and the rain falls in torrents. The transition from the hurricane winds immediately outside the central calm area to the calm area is usually very sharp, the passage as a rule being a matter of a few minutes only. The eye is sometimes an area of light breezes, but more commonly of absolute calm, without rain, and often with blue sky. The cross sea, however, is very violent and dangerous. Birds and sometimes butterflies have been found in the centre, usually in an exhausted state.

The central calm is most characteristic of tropical cyclones. It has seldom been reported from cyclones originating in temperate latitudes. Cyclones originating within the tropics may, however, move poleward into the temperate zones carrying their characteristic centre with them.

As the storm centre moves towards the observer, the wind is steady in direction, blowing nearly at right angles to the path of the storm. There is a heavy rain, usually accompanied by lightning and thunder. Just before the passage of the central calm the hurricane is at its height. Captains of vessels report the wind as indescribably furious. Everything on deck the wind can reach is blown to pieces. In several instances the boat at the weather davits has been torn from strong fastenings and carried clear over the ship. In short, we have reports of winds as severe as any vessel could live through; and beyond that we can only conjecture, from the great number of ships' "last seen" near the storm centre, how much more violent the hurricane may be.

In the majority of cases reported the ship passes almost instantaneously from the most frightful hurricane into absolute calm. Occasionally, however, after the first abrupt lull, the wind dies away gradually, so that it may be ten minutes or more before there is a perfect calm.

The calm is usually described as complete, making all allowance for effect of the contrast with the preceding gale, and there seems no reason to suppose that, in most cases, there is any appreciable motion of the air.

In some cases there was a thick haze during the calm. The clearing of the sky overhead, either wholly or partially, is one of the most marked features of the centre. The heavy rain of the hurricane ceases, and the sky clears either to pale blue sky with the sun or stars visible, or to a haze.

Distribution of cyclones according to season.—The next important subject to be dealt with is the origin and line of march of cyclones in the Bay of Bengal as determined by the season.

In the first place theory suggests, and experience confirms, the principle that cyclonic storms do not form over or near the equator. Squally weather with strongish gusts of wind during the squalls is by no means unusual, but these squalls never form part of a cyclonic circulation or whirl. All experience shews that they are only breaks or interruptions of comparatively brief duration in the ordinary weather of the season, and that they do not form part of a large and rapid eddying motion of the air, such as constitutes a cyclone. There is no record of a storm having formed to the south of Lat. 6° N., and it *may be accepted as a general principle that the lowest latitude in the Bay at which cyclonic storms are formed or met with is Lat. 6° N.*

The continued accumulation of cyclone records shews that the one feature which appears to be absolutely essential to the formation of a large cyclonic whirl or revolving storm in the Bay is an inrush of moist southerly winds. Such inrushes take place occasionally before the permanent setting in of the southwest monsoon. Hence cyclonic storms may occur at any time during the period when the southwest monsoon current blows steadily, and also during the period in which brief advances of southwest winds may occur over the south or the whole of the Bay at the commencement of the southwest monsoon, and hence at any time during the period April to December. They are rare in the limiting months April and December. *Hence it may be assumed that storms may occur at any time during the period May to November, and occasionally also in April and December.*

Another equally important generalisation is that the majority of the storms that occur in the Bay are generated in the Bay. There is not a single example on record of a cyclonic storm having formed in the Arabian Sea and passed across India into the Bay of Bengal. On the contrary several storms which originated in the Bay have passed across India into the Arabian Sea and re-developed into storms there. Such instances occur mostly in the retreating monsoon months of October and November. Similarly some of the typhoons which develop in the China Seas have crossed the Indo-Chinese Peninsula and entered the Bay of Bengal from the east. Most of them become very weak while passing over land, but re-develop into storms in the Bay under favourable conditions ; a few which pass across the narrow land strip of Tenasserim enter the Bay as full fledged storms. Approximately only about 12 out of 100 of the cyclonic storms in the Bay have had such a far eastern origin.

Hence nearly 90 per cent. of the cyclonic storms in the Bay of Bengal originate or are produced in the Bay itself.*

The Bay of Bengal has thus the peculiar advantage of being on the whole a small meteorological area, whose geographical position and features constitute it into mostly a self contained area in this respect. It is thus of special interest as the process of storm generation on either the large or small scale may be observed in it from the very earliest stages.

It may be laid down as a rule that cyclones or cyclonic storms can originate in, or advance over, any part of the Bay to the north of Lat. 6° N. near the coast or in the centre of the Bay or the Gulf of Martaban during the months of April to December.

There is a belief that the area to the west of the Andamans possesses certain peculiarities which favour the origin of fierce cyclones. This opinion is so widely spread that it is in newspapers, etc., frequently referred to as the birthplace of cyclones in the Bay. The only special feature is that this area is near the centre of the sea or water-surface comprising the Gulf of Martaban and the Bay of Bengal. Cyclones forming near the Andamans have hence a longer path before they reach land than if

*The figures given by Eliot for the percentage of storms with far eastern origin have been modified in the light of later knowledge.

they originated nearer to the coast, and hence, if the conditions are favourable, are more likely to develop into large and dangerous cyclones. This appears to be the main reason why the cyclones that form in that part of the Bay are larger and more intense than those formed near the head of the Bay, and are on the whole the most violent of all storms experienced in the Bay.

Experience shews that cyclonic storms and cyclones (more especially the latter) usually increase in intensity as they approach the coast, and that the lowest pressures are recorded in the calm centre shortly before reaching land. Hence the danger of being caught in a cyclone near the coast is increased by the exceptional strength of the storm when approaching it. The dangerous quadrant in cyclonic storms is the right advancing quadrant, and hence in the great majority of storms in the Bay of Bengal, it is the northwestern or northeastern quadrant.

The following paragraphs give a full statement of what is known of the distribution of cyclonic storms in the Bay of Bengal during the cyclone season, April to November.

April.—It has already been pointed out that cyclonic storms never occur in the Bay unless humid southwest winds) *i.e.*, the winds of the southwest monsoon) are blowing over the south of the Bay at least. These winds do not set in permanently until the middle or end of May, but previously to that date, southwest winds occasionally advance northwards for a brief period across the entrance of the Bay as far north as the Tenasserim coast and the south or centre of the Bay and then retreat again. These occasional bursts of southwest winds may occur at any time during the month of April, but are most probable in the latter part of the month. Sometimes these advances, if unusually powerful, give rise to cyclone storms The storms of April and also of the first fortnight of May, which form under similar conditions, to those of April (*i.e.*, during partial or irregular advances of the southwest winds over the south of the Bay) usually originate to the west or westnorthwest of the Nicobars, and advance in a westnorthwest direction to the Madras coast. *Cyclonic storms are of comparatively rare occurrence in the Bay of Bengal in April, the average frequency being once in three or four years. They form in the southeast of the Bay or the Andaman Sea. Those which originate in the Andaman Sea march northward to the Pegu coast. Those which form in the Bay proper are generated to the west of the Nicobars or Andamans, and generally move first northwards and then recurve in a northeasterly direction towards the Arakan coast.*

May.—This month not only witnesses occasional irruptions of southwest humid winds over the south of the Bay, but also in normal years the permanent advance of the great monsoon current into the Bay which usually occurs towards the end of the month. Hence cyclonic storms are a characteristic feature of the weather of the month, and are occasionally of exceptional strength and violence. If they form in the first fortnight, they are almost invariably due to a temporary advance of these winds, and hence originate in the south of the Bay or the Andaman Sea In the former case they usually march in a westnorthwest direction to the Coromandel Coast or by a curved track to the Arakan Coast. If they are generated during the great advance of the monsoon current in the latter half of the month, they generally form in the centre of the Bay, and advance in some northerly direction towards the coast of Bengal or Orissa.

Cyclonic storms are of comparatively frequent occurrence in the Bay during May. (about two in every three years). They usually travel in a northerly direction towards the head of the Bay and recurve to the northeast in the later stages of their journey. A few that form off the Coromandel coast travel westwards to that coast. There is about an even chance that a storm forming in this month will be of great intensity (i.e., *a cyclone*).

June.—The southwest monsoon is usually established early in the month over the whole of the Bay. This fact at once suggests that the cyclonic storms of the month in the Bay generally form near the head of the Bay.

Cyclonic storms are of frequent occurrence in the north of the Bay in June. They usually form to the north of latitude 19° *N. One or two such storms may be expected every year. It is an even chance whether a cyclonic storm which has formed in the Bay in June will pass in some northerly direction into Bengal or in some westerly direction across Orissa. The chief feature of the June cyclonic storms is the strong westerly or southwesterly winds or gales in their southern quadrants.*

July.—During this month the two monsoon currents, the Bengal and Bombay currents, blow most steadily and strongly. Cyclonic storms are of frequent occurrence

in the Bay, but are generally of feeble strength. They form mostly to the north of Lat. 19° N., and march in a westnorthwesterly direction across the Orissa coast.

Storms occasionally originate in Bengal itself, generally in east Bengal. As they form under like conditions, they march in the same general westerly direction. The chief feature in these land-formed storms, as in the corresponding sea-formed storms, is the strong westerly and southwesterly winds which prevail in their southern and eastern quadrants.

In July storms only occur in the north of the Bay. They are of comparatively frequent occurrence, an average of two or three occurring in every year. Their centres usually march in west or westnorthwest directions across the northwest angle of the Bay to the coast between Saugor Island and Gopalpur. The chances that a storm in this month will march in that direction are at least 10 *to* 1. *They are frequently feeble, but in about one case out of two or three they give rise to strong westerly and southwesterly gales at the head of the Bay, in which the force of the winds exceeds* 8.

August.—The southwest monsoon blows somewhat less steadily in August than in July, although the mean force of the winds is the same (*viz.*, 4·1). The winds are of greatest average force (5·4) in the area between 88° and 92° east meridians and 12° and 16° north parallels of latitude, or in the centre of the Bay.

Cyclonic storms are almost of as frequent occurrence in August as in July. Five out of every six form to the north of Lat. 19°. *The chief feature of the storm of August, as in July, is strong westerly and southwesterly gales at the head of the Bay, and the shift of wind is rarely large enough to indicate their cyclonic character except in the northwest angle of the Bay. The storms of the month occasionally advance northwards across the Bengal coast, but most frequently in west or westnorthwest directions across the Orissa or Ganjam Coast. The chances, based on previous experience, that a storm which forms in the month will advance in a westerly or westnorthwesterly direction are four to one.*

September.—The southwest monsoon blows less strongly and steadily over the Bay than in the preceding three months. It usually retreats from the greater part of upper India (including the Punjab, Rajputana, Central India and the United Provinces) during the third or fourth week of the month. Hence it does not extend, on the average, so far northwards as in the preceding months of July and August.

Cyclonic storms are as frequent in the Bay during September as in July and August, an average of two occurring every year. These cyclonic storms however, as a rule, form further south than in the previous two months, but usually to the north of latitude 16° *N. The chances are four to one that the centre of a storm which forms in September will advance in a westerly direction to the northwest coast of the Bay between Balasore and Cocanada. About one storm out of five advances in a northerly direction into Bengal. The great majority of these storms are of small intensity and resemble the storms of July and August in general character, and in the strength of the westerly and southwesterly winds in the south and east quadrants (as compared with the northeasterly and northerly winds in the north and west quadrants). Under exceptional conditions, the chief of which appears to be the earlier retreat of the southwest monsoon than usual from northern India, these storms occasionally are of great intensity and violence, and accompanied with hurricane winds. Hence cyclones are of occasional occurrence in September (and are most probable in the last fortnight). They form in the centre of the Bay, and the chances are about even that when such a storm has formed in the Bay in September, it will advance in a northwest direction to the west Bengal or Orissa coast or in a westerly direction to the coast of the Circars.*

October.—The southwest monsoon begins to retreat down the Bay in this month. In normal years, during the second or third week of the month, the wind direction recurves in the centre of the Bay through south, southeast and east, and arrives on the Coromandel coast as a northeast current giving northeast winds and frequent showers to the Coromandel coast districts. The reversion of the southwest monsoon current, and the consequent commencement of heavy rain with strong northeast winds in Madras, are usually regarded as the setting in of the northeast monsoon on the Coromandel coast. Hence, after this change occurs, northeast winds prevail more or less generally in the north and west of the Bay, and southwest winds in the south of the Bay. Between these areas there is an intermediate belt in which the winds are more or less variable and unsteady. In the district of predominant northeast winds the average wind force is 2·1, in the area of variable winds it is 2·8, and in the area of southwest

winds it is 3·0. It will thus be seen that the conditions in the Bay during the month are very different from those of the preceding three months, and that the prevailing wind directions shew a general tendency towards cyclonic motion about an area in the centre of the Bay to the west of the Andamans.

In consequence of this disposition of winds there is a marked tendency for cyclonic storms to form in the centre of the Bay furthest from land. There is hence a strong tendency for storms which form at this time to increase and become dangerous and extensive cyclones before they reach land.

The distribution of storms in the month of October is very irregular, and it is for this reason, as well as on account of the occasional great intensity of the storms, that October is on the whole the most dangerous and treacherous month of the year in the Bay.

Cyclonic storms occur slightly less frequently in the Bay in October than during any of the three preceding months. They rarely, if ever, form to the north of lat. 20°N. in the Bay of Bengal. They may originate in any other part of the Bay, but form most frequently in the centre of the Bay between the Andamans and the coast of the Circars and the north Coromandel coast or in the West Andaman Sea. If a storm forms in this month, the chances are probably about one to two that it will develop into a severe cyclone. The chances are about even that a storm generated in this month will advance westwards to the coast of the Circars, and if it does so, the chances are also about even that it is a feeble or a severe storm, or in other words a cyclonic storm or a cyclone. The chances are about one to three that if a storm forms in this month it will advance northwards to Bengal or Orissa, and if it does, the chances that it will be a severe cyclonic storm or a cyclone are about even. The chances that if a storm forms it will advance to the Madras coast south of Vizagapatam are also about one to two, but it if does, the chances that it will be a severe storm are probably about even.

November.—The general conditions in the Bay during this month are on the whole similar to those of the preceding month. The southwest monsoon winds retreat and cover a smaller area in the south and centre of the Bay than in October. The monsoon current recurves as in October, and continues to advance as a current giving northeast damp winds and much rain to the Coromandel coast districts. Northeast winds extend over the whole of the north of the Bay and are of average force 3·4, while the mean strength of the southwest winds in the south of the Bay is barely 3·0. The average strength of the winds in the intermediate belt of variable winds is practically the same as that of the southwest winds. Hence the conditions of the month indicate that storms will occur similar in character to those of the month of October but that they will probably form less frequently, and on the average further to the south, than in the preceding month.

Cyclones may form in any part of the Bay and Andamans Sea to the south of latitude 16°N. in the month of November. One to two storm may be expected every year in this month. The chances that a storm in November will be a cyclone are about two to one. If a storm forms, the chances that it will advance to the Coromandel coast are even. About one storm out of four that form advances to the coast of east Bengal or of Arakan. The part of the Bay which is most free from cyclonic storms in this month is the northwest angle of the Bay and the coast from Saugor Island to Vizagapatam. On the other hand the northeast coast of the Bay is liable to cyclones in this month.

December.—The southwest monsoon generally covers only the more southerly portion of the Bay during the early part of December, and usually withdraws from it in the third week of the month. This retreat is due to increasing weakness in the current. Hence, although in the very limited extent over which it prevails and in some other conditions it resembles the corresponding conditions of the month of May, the air motion in the south of the Bay in December is marked by great general feebleness, as compared with that of May, and hence differs entirely in the important feature of strength.

Storms are of comparatively rare occurrence in the month of December. They form in the south or southwest of the Bay of Bengal between the Ceylon coast and the Andamans and very rarely in the Andaman Sea. The chances are about even that if a storm occur in this month it will be a violent cyclone. The chances are three to one that a storm which forms in this month will advance in a westnorthwest direction to the Coro-

mandet coast south of Madras ; a few storms have advanced northwards to the Arakan or Chittagong coasts. Hence they are chiefly dangerous in the south-west of the Bay.

Barometric Indications.—These have already been discussed from a general standpoint in the preceding chapter. All that is now necessary is to summarize the facts and principles so far as they bear directly on the determination of the existence and character of cyclonic storms.

The movement of the barometer in the Bay of Bengal is, in ordinary weather, very regular, and is confined within narrow limits. In fine weather the most noticeable and important change is the regular up and down movement (occurring twice a day) known as the diurnal oscillation or the daily barometric tides.

When a cyclonic storm or cyclone is forming or has formed and is advancing over the Bay, it is usually merely the inner part of an extensive area of barometric depression and of cyclonic circulation.

If the storm be a small one, or what is termed a cyclonic storm, the depression or fall of the barometer below its normal height for the period is never large. It increases in amount from the outskirts of the depression to the centre of the storm, but even there it does not exceed two or three-tenths of an inch in the great majority of the smaller cyclonic storms in the Bay.

If the storm be a fierce and extensive cyclone, it consists, as has been already pointed out, of—

1*st.*—An outer storm area.

2*nd.*—An inner storm area.

3*rd.*—A calm central area.

In the outer storm area the barometer does not fall more than four or five-tenths below the normal height of the season. The inner storm area is one of comparatively small diameter, in which the barometer falls with excessive rapidity until the calm centre is reached. The barometer, it is believed, stands at nearly the same height over the whole central calm area at the same instant, but varies with the changes in the intensity of the storm.

If the reduced barometer reading is at any time during the cyclone season, April to November, a tenth of an inch below that normal to the time, the probabilities are two to one that a cyclonic storm has formed in the Bay ; if ·15 in. below it, the probabilities are at least three to one ; and if two-tenths of an inch below, it is practically certain that a cyclonic storm has formed.

In this manner, whilst he is quite in the outskirts of a cyclonic storm his barometer may strengthen and confirm the inference derived from the appearance of the sky and weather, the occurrence of squalls, etc., of the formation or existence of a cyclonic storm in his neighbourhood.

Another rule or principle, but one less simple in its application than the previous, is the following :—

If the barometer at or near the same place (or if proper allowance be made for change of place) falls a tenth of an inch in 24 hours in any part of the Bay, the chances are about 2 to 1 that a storm is forming in the neighbourhood of the place, or is approaching the place ; if it falls ·15 in. in 24 hours, the chances are about 4 to 1 that a cyclonic storm or cyclone is forming or approaching ; and if it falls two-tenths of an inch or upwards in 24 hours, it is almost practically certain a cyclonic storm is approaching the place.

Whilst a storm is forming, the barometer is frequently unusually high and steady beyond the outskirts of the incipient cyclonic storm. The same conditions of a high and steady barometer also frequently obtain in very fine settled weather. It is partly on this account, and partly on account of the very small fall of the barometer in the outer portions of cyclonic storms in the tropics that, as ordinarily used by sailors, that instrument frequently gives no indication to them of the approach of a storm until it is too late to be of any use.

Wind Indications.—One of the most important features of the weather is the occasional occurrence of what are called barometric depressions. These are really vast revolving eddies or whirls in the atmosphere. Just as an essential feature of an eddy in water is a difference of level at the upper surface of the water (greatest in the middle

of the eddy), so in an atmospheric eddy there is at the bottom of the eddy or at the earth's surface a difference of pressure which is greatest in the middle or interior of the eddy. The pressure or height of the barometer decreases from the outskirts of the eddy towards the interior. It is perhaps difficult to grasp fully that in a large cyclonic storm a vast mass of air 200 or 300 miles in diameter and ½ mile to 2 or 3 miles in height, is whirling or circulating round in a somewhat complicated manner, which, at and near the earth's surface, has been described as spiral, or vorticose. All observations of cyclonic storms shew that such, however, is the case. Such an eddy is called a barometric depression from one feature, *viz*, that the barometer is depressed below its natural or normal height in the eddy at the earth's surface, and that the depression increases towards the centre in a fairly regular manner. It is also called a cyclonic circulation, cyclonic storm or cyclone, from the manner in which the air moves or whirls in a regular manner round a definite point or small area in the interior of the eddy or whirl. The point in such an eddy where the barometer stands lowest, and which, so far as experience shews, generally coincides with the point or small central area about which the air circulates and towards which it is drawn, is called the centre. The shape or form of these atmospheric eddies is best shewn by the lines of equal pressure or isobars indicating and defining cyclonic storms in weather charts. They are very rarely circular, and are usually more or less oval and fairly regular in shape. They differ very largely in size, and also in the rate at which the air moves. Hence a cyclonic circulation may be either feeble, moderate or violent. If feeble, it is of little or no importance to sailors, except so far as they choose to use the winds for progress. If moderate, it may be called a "cyclonic storm," and if very violent, a cyclone or hurricane.

As suggested by Mr. Blanford, it appears to be desirable to retain the use of the word 'cyclone' for the most violent storms in the Bay of Bengal, and to employ the term 'cyclonic storm' for the less violent disturbances which are of frequent occurrence during the whole of the southwest monsoon period.

In cyclones and cyclonic storms the pressure slope or baric gradients are from the outside towards the centre, and, roughly speaking, coincide in direction with the bearing of the centre.

I have made measurements of the bearing angle, that is, the angle between the direction from which the wind comes and the bearing of the centre, for nearly every cyclone which has occurred during the past twenty-five years. Although there are considerable differences between single measurements, the average of a large number of such measurements gives an angle of almost constant value

To determine the bearing of the centre at any position within a cyclonic storm face the wind exactly, then the centre will be between 10 *and* 11 *points to the right hand* (*or, more exactly,* 10½ *points*).

With the one important exception, *viz.*, of the northeast winds in the northwest quadrant in the case of storms advancing to the Orissa or west Bengal coast, I believe the preceding rule is exact enough for the ordinary requirements of practical men and sailors who require a fairly definite rule on the subject and have to apply it under circumstances when exact measurement is almost an impossibility. It should, of course, be remembered that there may be real exceptions due either to irregularity in the cyclonic circulation itself, or to features not yet fully recognized, and that there are apparent exceptions, due to errors in the measurement of wind direction on board ships.

Buchan, in his *Hand-Book of Meteorology*, states—

"The relation between the wind direction and bearing of the centre of a barometric depression is what is known as Buys Ballot's Law of the Winds. According to this distinguished meteorologist, if a line be drawn in the direction from which the wind comes, and another from the place of observation to that of least pressure, the angle is generally from 120° to 100°. This is unquestionably the general direction of the wind in storms, but the angle is frequently as large as 135°, especially where the winds become lighter on approaching the central space of least pressure, and on rare and peculiar occasions it is less than 100°. The wind in cyclonic storms blows round the area of low barometer in a circular manner, and in a direction contrary to the motion of the hands of a watch, with, and be this particularly noted, a constant tendency to turn inwards towards the centre of least pressure. Also, the greater the force of the

wind at any place, the more nearly is the direction indicated, by the principle stated above, approximated to ; and where the directions show any material departure from the general law, such winds are almost invariably light, and consequently more under local influences, which tend to turn them out of their course. Hence in cyclonic storms the winds circulate round the region of least pressure ; or, to state it more accurately, the whole atmospheric system appears to flow in upon the central area of low pressure in an in-moving spiral course. This peculiarity is common to all European storms I have yet examined ; and it should be particularly noted that it is no mere theory or opinion, but a simple statement of what has been constantly observed."

Rate of advance of cyclones.—The rate of motion of cyclonic storms differs very considerably even for storms of the same class, and also for the same storm at different periods of its existence. In the earlier stages of cyclones and cyclonic storms in the Bay, the velocity is generally less than 4 miles per hour. After they have fully formed, they advance in some cases with a velocity, which is uniform during the remainder of their progress at sea ; but, in other cases, with a velocity which increases rapidly as they approach land. The average velocity of storms fully formed appears to be from 10 to 12 miles per hour, and this is, perhaps, the best rule for the sailor to assume. Several severe storms of recent years have advanced at the rate of 15 miles when approaching land, and the Backergunge cyclone travelled with the very great velocity of about 25 miles per hour across the mouth of the Meghna. There appears to be no direct relation between the intensity of a storm and its rate of progress, and no general rule has yet been suggested which will enable the sailor to estimate from such observations as he usually is able to take during a storm, its rate of motion.

CHAPTER IV.—BRIEF ACCOUNT OF FIVE TYPICAL CYCLONIC STORMS

THE AKYAB CYCLONE OF 14TH TO 17TH MAY 1884

This small cyclone is an example of a class of storms which are of almost annual occurrence. These storms are formed in the month of May, when the southwest monsoon current proper enters and advances up the Bay of Bengal.

They form usually in the centre of the Bay and travel first in northnorthwesterly or northerly direction and later recurve towards the northeast. The majority strike the Bengal or Burma coasts, while a few cross the Orissa and Madras coasts.

The present storm, marched northwards and then recurved and struck the Arakan coast.

Brief summary of chief facts of the storm.—The storm formed on the 14th and 15th to the west of the Andamans, and in front of the first local advance of monsoon winds up the Bay. It moved northwards on the 15th and 16th and on the 17th recurved through NNE to NE, and finally crossed the Arakan coast at Akyab about 9 p.m. on the 17th. It broke up shortly afterwards without crossing the Arakan hills. The storm area was oval-shaped, the longest diameter on the 16th and 17th approximately coinciding with the direction of motion of the storm.

There are no data for the determination of the magnitude of calm area at the storm centre in this storm, beyond the fact that there was a lull of five minutes at Akyab when the centre was passing over the station. As the storm was then moving at the rate of 15 miles at least, this would prove that the breadth of the central area was at least 1¼ miles. The lowest barometric reading actually recorded during the progress of the storm was 28·83″ on board the *Pemba*, about 20 miles from the calm centre, at 2 hrs. on the 17th.

Weather previous to the formation of the cyclonic storm.—The history of the cyclone commences on the 11th of May. Over and near the equator the weather was unsettled and squally. Skies were overcast, and heavy showers of rain were falling at intervals. Over a narrow belt near the north and west coasts of Ceylon there were strongish winds blowing from the sea to the land. Over the whole of the Bay proper, winds were very light and variable, weather sultry and the sea smooth, and there was no sign or indication of stormy or squally weather. During the next 24 hours the only change in the weather was the advance of squally whether as far north as Lt. 5° or 6° N. In this area the squalls were more severe than on the 11th, and rain was falling more or less steadily and continuously. This advance of a humid, squally current of air is further confirmed by the change in the weather which had taken place during the previous 24 hours in Ceylon. The skies clouded over in that island, winds strengthened, and heavy rain began to fall on the afternoon of the 11th. Colombo, for example, received 3·42 inches during the day. The humid current in the south of the Bay continued steadily to advance northwards, and at noon of the 13th had reached Lat. 9° or 10° N. The winds increased in strength, squalls were more frequent and severe and the rainfall more continuous and intense. With the northward extension of the strong, humid southwest monsoon winds, the accompanying atmospheric disturbance reached a portion of the Bay where under favourable conditions squally weather may develop into a cyclonic storm as on the present occasion.

History of the cyclonic storm—*May 14th.*—This change occurred, as will now be seen, during the next 24 hours. A largish fall of the barometer had taken place during the previous night at Port Blair and Nancowry. The winds had shifted during the previous 48 hours from southsoutheast to southsouthwest at Nancowry, and from northwest to southeast at Port Blair, and increased very considerably in strength and were nearly three times as powerful on the morning of the 14th as on the 13th. The wind directions had shifted on the west coast of the Bay south of Vizagapatam round from southwest to northeast and northwest Strong westerly winds were blowing steadily at the Ceylon ports. These winds show clearly that a cyclonic circulation was now established over the centre of the Bay, and the history of the cyclone hence dates properly from this day.

Heavy rain continued to fall in Ceylon, and moderately heavy rain set in at Port Blair and Nancowry, which were now receiving their first showers from the

advance of southwest winds. The wind directions and barometric observations recorded on board ships, as well as at the coast stations, show that a barometric depression, the centre of which was at noon in about Lat. 11°N., Long. 89½E., had begun to form, over which the air was moving cyclonically. The logs of the vessels in the Bay indicate that the weather in the south of the Bay was becoming more and more unsettled and threatening, the squalls more severe and the winds cyclonic in intensity, as well as in direction. Hence we see that the disturbance which was now developing into a cyclonic storm had commenced as squally weather and heavy rain near the equator, and that it had extended northwards and increased in severity and violence, and when it had advanced beyond Lat. 8°N. or 9°N. it had changed in character. Hitherto there had been no centre of action. The weather had been squally, with heavy rain showers, but the winds had not shown regular and continued convergence to a centre of indraught. During the previous 24 hours a definite centre, about which the actions were taking place, had been established. The barometer fell most rapidly at and near it, rain was heaviest in its neighbourhood, squalls were very violent, and the winds between the squalls not only increased in force, but showed that indraught to a centre which is the characteristic of a cyclonic circulation and storm.

May 15th.—The observations extracted from the logs of the vessels show that the centre of the cyclonic storm was at noon in Lat. 13°N., Long. 90°E., so that it had advanced about 150 miles during the previous 24 hours.

May 16th.—The observations of the 16th show that the disturbance had now become a violent and dangerous cyclonic storm. The various observations, when charted, established that the centre of the storm was at noon of the 16th in Lat. 15°40′N., Long. 90°45′E., and was travelling northwards at a rate of nearly nine miles an hour. It was at that time about 300 miles due west of Diamond Island and Cape Negrais. Very strong winds prevailed over the Bay, to the south of the depression and storm area, and winds of hurricane force in the inner storm area, whilst further north they diminished rapidly in strength and at the head of the Bay were very light, and almost the same in direction on the morning of the 16th, as if the storm had not existed. The weather to the north and northwest was in remarkable contrast to that in the centre and south of the Bay. The *Bhundara*, anchored off Puri, had light airs. The *City of Khios* in Lat. 16°46′N., Long. 86°10′E., at noon, had light north winds of force 2 during the whole day. Skies were clouded, but the weather was fine throughout. The *Clan Mackintosh*, in Lat. 15°11′N., Long. 82°29′E., was, like the *City of Khios*, advancing northwards at about the same rate as the storm. She experienced very hot and sultry weather, with overcast skies and light winds.

May 17th.—The various observations show that the centre of the storm was approximately in Lat. 19°N., Long. 91¼°E., at noon. It had therefore advanced about 240 miles during the previous 24 hours, *i.e.*, at the rate of 10 miles per hour. Strong winds prevailed over the whole of the Bay to the south of the disturbance. They fed the storm, but they did not form an integral part of the cyclonic circulation, and the direction of the centre could not have been accurately ascertained from them. Winds were strong for some distance to the north and west of the centre, but at distances of 150 miles and upwards they were exceedingly light, and in the neighbourhood of the Bengal and Orissa coasts were much feebler than the ordinary winds of May. The chief indication on the Bengal coast of bad weather to the southward was the very heavy swell which came up from the southeast.

The centre advanced in a northnortheast direction to the Arakan coast on the afternoon of the 17th.

Winds increased slightly in force on the 16th at Akyab. The weather began to be squally with rain, on the morning of the 17th and the sea to rise. The barometer commenced falling at 10-30 a.m., and at mid-day the squalls became more frequent and violent. The wind increased to a gale at 4 p.m. and the weather was then very threatening, with frequent furious squalls. The squalls blew with terrific force, and heavy continuous rain fell after 7 p.m. and the sea continued to rise. The barometer fell to 28·98″ at 8-45 p.m. when the storm was at its worst and blowing with enormous force from the eastsoutheast. A short lull of five minutes occurred at 9 p.m., during the passage of the calm area, which was apparently of small extent, about 1½ miles in diameter, judging from the rate of motion of the cyclone at the time. After this the wind suddenly shifted to southsouthwest. The weather

began to moderate very slowly afterwards but the wind blew hard all night, with heavy and violent gusts.

May 18th.—The cyclone was now advancing directly to the Arakan Hills, which are of considerable elevation, averaging 3,500 feet and rising in their highest peaks to 7,000 feet. They proved to be too large an obstacle for the storm to surmount, and caused a rapid destruction of the cyclonic motion. Before 10 a.m. of the 18th the storm had completely broken up and disappeared. Light irregular winds and calms prevailed on the Arakan coast, and moderate southwest winds (decreasing in intensity as the day advanced) with cloudy and hazy weather over the Bay generally.

Storm wave.—A storm wave broke over the Arakan coast and inflicted much loss upon the crops and grain stored up. About 100 people are reported to have been drowned or killed by falling houses during the storm.

THE MONSOON STORM OF 26TH JUNE TO 4TH JULY, 1883

This is an example of the class of storms which are generated during the rains (that is, between June 15th and September 15th). The great majority of these storms form in the immediate neighbourhood of the land, and hence ships coming up the Bay mainly experience the weight of the westerly and southerly winds which feed into them. They give strong westerly gales near the head of the Bay to vessels bound for the Hooghly and the storms are sometimes described as westerly gales.

Summary of facts.—This storm began to form on the 25th June at the head of the Bay after a short break in the rains which followed the first large advance of monsoon winds up the Bay into Bengal. It remained almost stationary on the 26th and 27th, and began to move very slowly to the westward on the 28th and crossed the Balasore Coast a few miles to the north of Balasore about midnight of the 29th. It marched in a westerly direction across the Orissa hills into the Central Provinces, diminishing to some extent in intensity and moving somewhat irregularly. It, however, began to draw large supplies of vapour from the Bombay Coast, and again increased in strength, and continued its march across the head of the Peninsula at an average rate of about 15 miles per hour. It advanced through Cutch, and thence passed out into the Arabian Sea on the evening of the 3rd July, and was some distance to the south of Karachi on the morning of the 4th. It passed over the steam-ship *Oriental* on the evening of the 4th in Lat. 24°4′N., Long. 63°30′E., or 220 miles west by south of Karachi. Nothing is known of its history after that date, but it probably broke up shortly afterwards. The storm had hence an unbroken existence of at least ten days. It presented comparatively small differences of intensity at different periods, taking into consideration the very different conditions of its existence at sea, and afterwards whilst advancing across the hills, plateaux and river valleys of the head of the Peninsula. The lowest recorded reading of the barometer was 29·140″ (·462″ lower than average) at the Sandheads on June 29th.

Weather previous to the formation of the storm.—There was a partial cessation of the rains in Bengal. The air became drier, skies were less clouded, and the winds fell off in strength. In the Bay, southwest monsoon winds prevailed everywhere, but they were nowhere of force greater than 3 or 4, except during occasional rain squalls, such as occur at intervals during the prevalence of the south-west monsoon in the Bay.

The observations of the 25th June showed that a marked change in the weather was commencing. The barometer in south Bengal was two-tenths of an inch above its normal height. Winds were very unsteady and variable in Bengal and over the north of the Bay. Heavy rain squalls and dark overcast skies prevailed over the southeast of the Bay between Lat. 14° and 19°N., and close sultry weather with calms or light airs, clear skies and a smooth sea to the north of Lat. 20°N.

The winds in the south and centre of the Bay increased in force during the day and weather became squally and unsettled near the head of the Bay, on the 26th. The *Comilla*, in Lat. 22° 21′N. Long. 91°50′E., had squally weather with very heavy continuous rain during the afternoon and evening. These were the first indications of the impending storm. The weather became more unsettled and threatening in appearance during the day, heavy rain began to fall in the north of the Bay, the barometer fell rapidly, and winds began to draw into the area of falling barometer from the north as well as the south.

Heavy rain also commenced in the neighbourhood of the Arakan coast and increased the force of the southwest winds in the north of the Bay, and the disturbance thus initiated was shortly afterwards followed by the formation of a whirl near the head of the Bay. The winds on the Bengal coast, although still feeble, settled down to northeast, the usual indication during the rains of the formation of a cyclonic whirl at the head of the Bay.

History of the storm.—*June 27th.*—This whirl gained rapidly in force during the night of the 26th, and on the morning of the 27th it had developed into a small but dangerous storm. The chief features of the storm at this time were the violent winds in the southeast and east quadrants. In the western and northern quadrants skies were overcast with rain, and weather was unsettled with occasional squalls, but the winds were as yet feeble, varying in force from 1 to 4 or 5, except perhaps in the immediate neighbourhood of the centre.

June 28th.—The storm continued to increase in intensity during the night of the 27th, and on the morning of the 28th the barometer had probably fallen to 29·00″ at the centre, as readings between 29·1″, and 29·2″ were recorded on board ships at distance of 20 to 40 miles from the centre during the day. The various observations taken on board ships indicate that the centre at 10 a.m. of the 28th was in Lat. 21°N., Long. 88°45′E., and moving west by north at a rate of about 3 miles per hour. The weather over the north of the Bay was now very wild and stormy.

The contrast between the violent winds and furious squalls in the southern and eastern quadrants at considerable distances from the centre (up to 150 or 200 miles), and the moderate winds and squalls at distances of 30 or 40 miles in the northern and western quadrants, was one of the most conspicuous features of this storm, as it is probably of all the small cyclonic storms of the rains proper.

June 29th.—The observations of the 29th show that the barometer had fallen rapidly in southwest Bengal and Orissa, and was nearly half way an inch below as normal height in June.. Winds were from two to four times their ordinary strength in June, and very heavy continuous rain had fallen during the preceding 24 hours over the whole of Orissa and southwest Bengal. These observations and the logs of vessels show that the storm continued to increase in extent during the night of the 28th, and covered a larger area than it had hitherto done. It intensified slightly, but there is no evidence that the barometer fell below 29·0″ at any time during the storm. The lowest recorded readings were 29·14″ at the Upper Gasper light-ship at 10 a.m., and 29·108″ at 4 p.m. of the 29th. The storm centre continued to drift slowly to the westward during the night of the 28th, and was in Lat. 21° 30′ N., Long. 87°55′E., at 10 a.m., of the 29th, or about 35 miles to the west by north of its position at 4 p.m., on the previous day, and was advancing at a rate not exceeding 3 miles per hour. It had passed between the Intermediate and Upper Gasper light vessels, and was about 5 miles to the west. The vessels in the north of the Bay continued to experience violent cyclonic winds and a dangerous sea. All the ships' logs agree in assigning a force of 10 and 11 to the winds in the southern and eastern quadrants. At Saugor Light-house, which was only 20 miles to the north of the centre at 10 a.m., moderate winds were felt, and at the Upper Gasper light-vessel, not more than 5 to 10 miles to the north of the centre, the winds were of force 5 to 6.

The captain of the *Comet* floating light-vessel thus describes the weather on the 29th—"Weather was very threatening in the morning, and a heavy sea came up from the southeast. The wind was very variable, shifting all round the compass. Rain-squalls passed up frequently. At midnight it was blowing a furious gale". The captain of the *Meteor* floating light-vessel describes it as follows :—"The sea was very rough, and a squall from southwest came up at 8 a.m., of the 29th. Frequent heavy rain-squalls passed over the vessel. The wind shifted to southwest at 10-30 a.m. The barometer began to rise at 2 p.m. During the evening a strong southwest gale blew, and frequent terrific rain-squalls passed over the vessel.".

June 30th.—The storm centre crossed the Orissa coast between False Point and Balasore during the night of the 29th and was advancing through Orissa on the morning of the 30th. Its position at 10 a.m. of the 30th was in about Lat. 22°0′N. and Long. 84°0′E. It was hence travelling much more rapidly than hitherto. The

barometric depression at the centre was not so great, and the air motion was not so regular as at sea. This was evidently due to the resistance and action of the Orissa hills.

The above account illustrates fully the chief features of the more dangerous storms of the rains proper in the Bay of Bengal. They commence to form after a partial cessation of the rains in Bengal. Heavy rain begins to fall, generally near the Arakan coast or at the head of the Bay. This causes a greater inrush of moist winds from the south, which not only prolongs and intensifies the rainfall, but generally sets up a whirl near the head of the Bay, which, if conditions are favourable to its growth, increases and intensifies and becomes in the course of a day or two a dangerous storm. The most prominent feature of these storms is the very violent winds and furious squalls in the southeast quadrant which extend to very considerable distances from the centre. The storm moves very slowly in the earlier stages, and hence the stormy weather or westerly gales attending them may continue for several days; but when the cyclone is fully developed it generally moves or shoots off rapidly to the Orissa coast (or the Bengal coast, but much more rarely), and very shortly after it passes landwards the weather begins to improve at the head of the Bay, and the winds decrease in force, and in a short time normal or ordinary southwest monsoon winds (force 3 to 5) are again established at the head of the Bay.

July 1st.—The history of the storm after it reached the Orissa coast is given more briefly. The centre travelled at a mean rate of about 15 miles per hour on the 30th, and was in about Lat. 22°N., Long. 81°E, at 10 a.m., of the 1st. The storm gave excessive rain to Orissa, and very heavy rain fell in the districts of the Central Provinces through which it passed on the 1st, which flooded the rivers and carried away bridges on the railways and roads, and interrupted traffic.

July 2nd.—The storm passed out of the Central Provinces into Central India on the morning of the 2nd. The centre was near Indore at 10 a.m., in Lat. 22½°N., Long. 76°E., so that it had advanced at a mean rate of about 14 miles per hour during the previous 24 hours.

July 3rd.—The storm crossed through Gujarat into Cutch, and was between Bhuj and Rajkot in Lat. 23½°N., Long. 69¾°E., at 10 a.m., of the 3rd. It had continued to give excessively heavy rain to the districts through which it marched. At Rajkot 9·85 inches were recorded on the 3rd. The storm had thus advanced unbroken across the head of the Peninsula from the Orissa coast to Cutch, a distance of 1,400 miles, in about 80 hours. It was now in the immediate neighbourhood of the Arabian Sea, into which it passed during the afternoon of the 3rd.

July 4th.—The following is the account of the storm given by the captain of the *Oriental* :—

"I experienced a very heavy cyclone on the night of the 4th July in Lat. 24°14′N., Long. 63°30′E., at 8 p.m. I had a light westerly breeze, with the usual southwest swell on the morning and afternoon of the 4th and the barometer was steady until 9 p.m., at which hour the wind began to increase slightly, hauling northerly. As I noticed the glass was falling rapidly, I gave the order to take in all sail. While clewing up the fore-topsail, the whole force of the cyclone struck her, carrying away fore-topsail, foresail and awnings fore and aft. I, at once, eased down to keep her before the wind till the saloon sky-lights could be secured, as I was afraid to bring her to the wind till they had been secured. At 11-30 p.m., a sea carried away both quarter boats on the starboard side. At midnight I brought the ship to the wind and sea. The reading of the barometer at that time was 28·56″. Violent winds continued until 4 a.m., when the wind commenced to moderate. The sea continued very heavy, and I was not able to stand on my course until noon ".

It would appear from this account that the storm not only intensified again after leaving the coast, but that it moved more slowly than while crossing the land. In both respects it agrees with what has been observed in other storms that have passed into the Arabian Sea from the Bay of Bengal.

THE FALSE POINT CYCLONE OF 19th TO 23rd, SEPTEMBER 1885.

The False Point cyclone of 1885 is a very remarkable example of the small, but

very intense and severe cyclones which occasionally occur in the Bay. The lowest barometric reading (27·135″) taken at the False Point Light-house during the passage of the storm centre over it is lower than any previously recorded verified barometric reading at sea level. The cyclone was in character a storm of the transition period—October to December—rather than of the rains. It, however, occurred at least a fortnight earlier than any storm of similar intensity has been previously recorded, and is therefore in several respects unique.

Brief summary of chief facts of the storm.—The False Point cyclone was generated in an area of calms and light unsteady winds to the southwest of Diamond Island on the 17th and 18th. Excessive rain fell in this area, and the storm developed with unusual rapidity on the 19th in about Lat. 15°N., Long. 92½°E. It was fully formed on the afternoon of the 19th and marched in a northwesterly direction. The centre advanced rapidly without change of course to the Orissa coast, which it reached about 6 A.M. on the 22nd. The central calm area passed over the lighthouse, and lasted for half an hour. The storm advanced across Cuttack and the Orissa hills, but decreased very rapidly from this period. It gave a deluge of rain to those hills, and thence passed through Chota Nagpur on the 22nd and Bihar on the 23rd, and died out in north Bihar on the morning of the 24th, after having given heavy rain in Chota Nagpur and moderately heavy rain in Bihar. During the latter part of its existence it moved very uniformly, and at a rate averaging 13 miles per hour.

The wind at False Point *remained steady at northeast during the whole period of approach of this storm until within a few minutes before the calm area reached the station when it shifted suddenly to northwest.* As the storm advanced in a northwesterly direction to False Point, the angle between the wind direction and centre was hence throughout 90°. This is another example of the peculiar wind relations which appear to obtain at False Point and probably over the adjacent portion of the Bay.

Weather previous to the storm.—The storm began to form, so far as can be judged from the reports, on the afternoon of the 18th of September or the morning of the 19th. The weather for some days previously in Bengal and northern India was such as accompanies a partial break of the rains. Rain had practically ceased to fall in upper India.

September 18th.—The logs of a large number of vessels show that in the north of the Bay fine clear weather, with light southwesterly winds (but somewhat unsteady in character) still prevailed. The only part of the Bay area for which the information is somewhat scanty and imperfect is the Andaman Sea. The observations at Port Blair and Nancowry, and at the Burma and Tenasserim coast stations, as well as those taken on board ships in the Bay, shew most clearly that there was no cyclonic motion of the air in that part of the Bay. Squally weather with frequent heavy rain-showers prevailed over a large portion of the south and centre of the Bay, and the disturbed weather was extending northwards and invading the area of light variable winds and hot sultry weather to the west of the Pegu coast, so that a heavy bank of clouds had collected or formed apparently in the area over which the storm was generated during the next 24 hours. The observations at the Bay Islands confirm these statements to some extent. Thus, at Port Blair heavy rain was falling, skies were gloomy, and winds had increased very considerably in force. They were blowing from west or southwest, and were hence normal in direction, and such as precede and accompany the formation of a cyclone to the west of the Andamans. Moderate rain had also fallen at Nancowry. Little or no rain was falling in Burma.

The observations hence show that a considerable increase in the strength of the southwest monsoon winds had occurred over the south of the Bay. Weather also became unsettled and squally, and heavy rain began to fall in some parts of the south and centre of the Bay. So far as can be judged, this rainfall was heaviest at and near Port Blair, and it was in the sea area to the north of the Andamans that the cyclonic storm originated and was generated during the next 24 hours.

Account of the storm.—In the south of the Bay the southwest air current continued to increase in volume and intensity, and its northward advance over that area to the centre of the Bay (more especially the eastern half) was now accompanied with

very unsettled, squally weather. The only vessel near and within the area in which the storm was forming on this day was the ship *Governor Wilmot*. Her account shows the inception and increase of the storm during the day. She was in Lat. 14°27′N., Long. 92°8′E. at noon, and proceeding slowly westwards on her course from Diamond Island to Calcutta. The following extracts giving the weather experienced, are from her log :—

"Early morning.—Northwest winds, force 6. Squally-looking, with smooth water. Constant rain. Morning.—Increase breeze, with constant heavy rain. Noon.—Wind very unsteady ; constant rain. Very heavy rain at 4 P.M. Wind increased at 8 P.M. to force 8 from the west, and blew a whole gale".

The above account agrees with the general experience of cyclone generation in the Bay. Heavy continuous local rain in an area of light unsteady winds, fed by strong southwest monsoon winds prevailing to the south, is always the chief and most prominent feature. The barometer usually commences to fall simultaneously with the heavy rainfall. Winds are for some time afterwards unsteady, although increasing in force, and are interrupted by squalls, which increase in frequency and in intensity. After some time regular cyclonic motion of the air is established which, if the rainfall continues and increases in amount, develops into rapid and violent cyclonic motion on the large scale over the storm area. This change in the present storm appears hence to have gone on continuously on the 19th in a small portion of the Bay to the southwest of Diamond Island, and north of the Andamans, and on the afternoon and evening of the 19th the cyclonic storm was fully initiated.

September 20th.—The logs of the ships furnish abundant evidence of the unusually rapid growth of the storm. They show that the centre at noon of the 20th was in Lat. 15°30′N., Long. 91°30′E. or Long 92°E There were a large number of vessels to the south and west of the centre during the day. Their logs all record that unsettled squally weather, with gloomy threatening skies, extended over the greater part of the Bay south of Lat. 18°N and east of Long. 86°E., but that strong winds (or winds exceeding 8 in force) were only experienced to a distance of 60 or 80 miles from the centre except in the south quadrant where they obtained over a large portion of the south of the Bay.

The *Governor Wilmot* was nearest to the centre in the morning and at a distance of 60 miles to the northnortheast at noon. Her log for the day is as follows :—

"4 A.M.—Wind westnorthwest, force 10. 8 A.M.—Wind west, force 11, blowing a hurricane. Sky black, with thick low clouds ; constant heavy rain. Barometer fell rapidly during the morning and stood at noon at 29·5″. The sky was very thick and black at noon, so that it was more like night than day. 4 P.M.—Wind southwest, force 11. 6 P.M.—Weather began to improve ".

September 21st.—The various observations indicate that the centre at 10 A.M. of the 21st was in Lat. 17°30′N., Long. 89°30′E. or 89°45′E., so that it had travelled 180 miles to the northwest during the previous 24 hours. In Bengal skies were much less clouded than they had been previously.

The storm moved more rapidly during the afternoon and night of the 21st, and reached the Orissa coast early on the morning of the 22nd. It apparently grew rapidly in intensity during the day, but the inner storm area was not much enlarged, so that it continued to present the same features as on the 20th of a small area of not more than 50 or 60 miles in diameter in which the winds raged with hurricane force, whilst beyond it they decreased rapidly in intensity, and at distances of 80 or 100 miles from the storm centre were comparatively feeble.

The following gives extracts from the logs of those ships which were involved in the storm during the 21st. The first was the *Calcutta*, which was about 50 miles to the south of the centre at noon of the 21st. The account in her log is brief :—

"Winds changed gradually from northwest to west by south and then to southsouthwest and finally to south by east. Terrific squalls at noon with a regular downpour of rain. The sea in the evening seemed to come from all quarters ".

This vessel passed from the southwest to the southern quadrant, but was never nearer the centre than about 50 miles.

The *Quang Tung* left the Sandheads on the 19th for the Andaman Islands and her course took her directly through the storm area. She was nearest to the centre at 4 P.M. of the 21st, when she was about 70 or 80 miles to the north of the centre and in the outer storm area. The following extracts are from her log of that day :—

"4 A.M.—Sea smooth. 8 A.M.—Wind eastnortheast ; force 5. Moderate northeast sea and swell. 9-45 A.M.—Wind and sea rapidly increasing. Very heavy southeast sea. Noon.—Wind east by south, force 8. Very heavy sea. 4 P.M.—Wind east by south, force 9. 8 P.M.—Very hard squalls from the eastward".

September 22nd.—The tug steamer *Britannia* was advancing slowly to the mouth of the Hoogly and was off the Orissa coast on the 21st. She was hence right in the track of the cyclone and experienced its full weight on the night of the 21st. The following account is extracted from her log :—

"21st, 4 A.M.—Wind eastnortheast, force 3. Noon.—Barometer 29·6″, wind northnortheast, force 6. 4 P.M.—Wind northeast, force 6. From noon the wind increased in force, and at 1 A.M. of the 22nd was blowing with hurricane force. Barometer stood at 28·2″ (corrected reading 28·16″) from 1 A.M. to 3 A.M., when there was half an hour of calm weather. The wind then came down from the west (backing to southwest) with terrible force until 6 A.M., when it began to moderate, During the storm the fore and main top-gallant masts and yards were lost, and the whole suit of sails blown away from the yards, except the main sail and jib ".

The *Booldana* on the 21st was lying off False Point at the anchorage ground. The following account of the storm is taken from her log :—

"At 4 P.M. wind was from eastnortheast, and there was a heavy sea running with dirty squally weather. At 8 P.M. wind northeast, force 9. Sea increasing. At midnight strong gale, with *very hard dry* squalls. 2 A.M. of the 22nd.—Gale increasing with slight rain. 3-30 A.M.—Heavy squall ; wind blowing a very heavy gale. 4 A.M.—Barometer began to fall very rapidly, and wind and rain increased. 5 A.M.—Wind northeast. 6-15 A.M.—The weather cleared up with clear sky overhead, but round the horizon all dark. 7 A.M.—Barometer at its lowest 27·4″ (uncorrected) The gale came down from the opposite quarter (southwest), making it impossible to stand on deck without holding on. 9-45 A.M.—Force of the gale gradually abating. Noon.—Fresh squalls from southwest".

The weather in other parts of the Bay was more or less squally with strongish winds and a high sea. The sea was especially high in the shallow water at the head of the Bay.

The lighthouse at False Point is situated about 7 miles to the southsouthwest of the anchorage ground in the harbour. The calm area passed over it very shortly after it reached the *Booldana*. The following is the account of the weather, as given by the lighthouse-keeper :—

" The weather began to assume a threatening appearance between 4 and 5 P.M. of the 21st when the wind was from the northeast, and blowing in squalls with an overcast sky, and heavy banks of clouds rolling up from the northeast. The weather continued the same, with the wind increasing in force and squalls more frequent until between 1 A.M. and 2 A.M. of the 22nd, when it blew a gale. At 4 A.M. the wind had increased to a hurricane, and the squalls were most terrific, with blinding sheets of rain. The wind was still from the northeast, and the barometer falling rapidly. At 6-30 A.M. the wind hauled to the northwest, and continued to blow a hurricane for a few minutes, when it suddenly lulled and became almost calm. At 6-50 A.M. the wind came down with redoubled force from the westsouthwest, the gusts being most terrific. From 7 A.M. to 10 A.M. the barometer rose rapidly and the wind gradually moderated to a gale, and at noon it blew a fresh breeze from the southwest, with squalls".

The observations of pressure, wind and weather recorded at False Point during the passage of the storm are shown in Fig. 3.

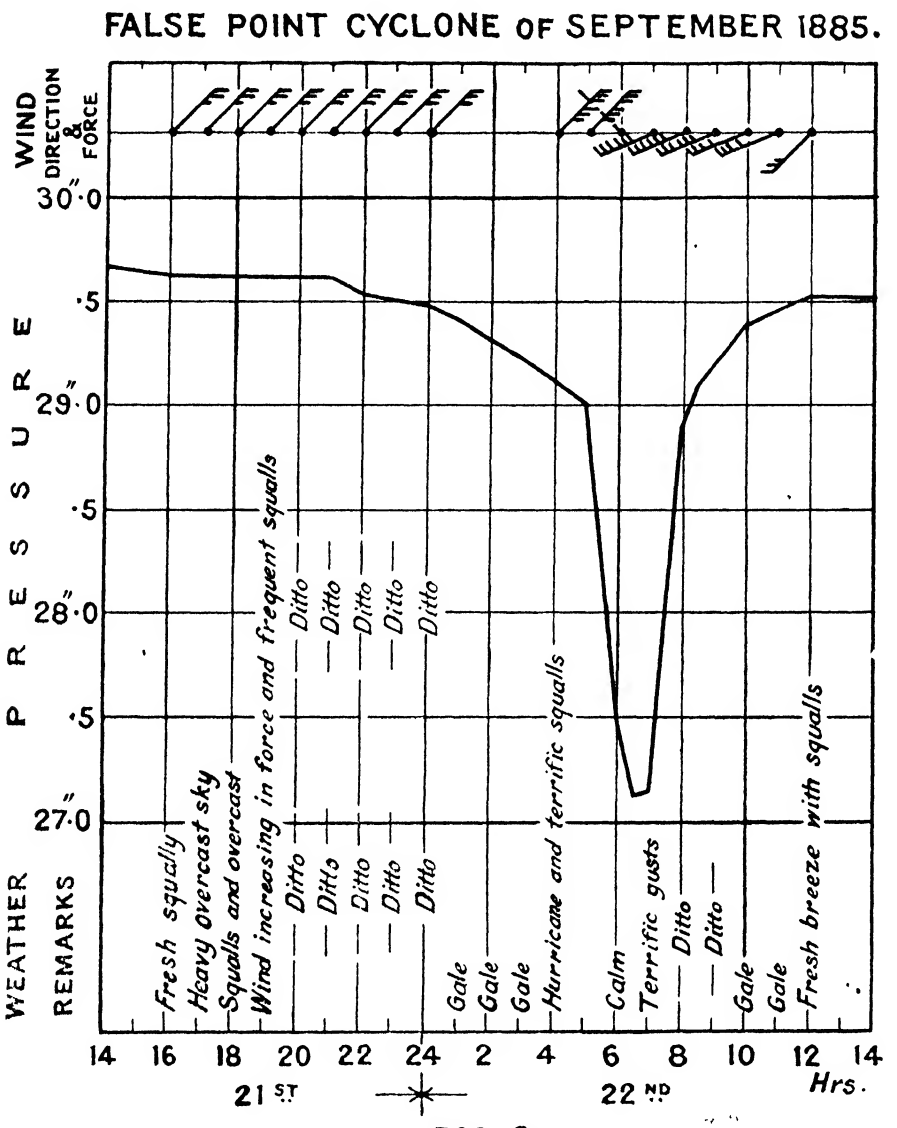

FIG. 3.

The storm advanced in a northwesterly direction during the day across north Orissa and Chota Nagpur, and gave very heavy rain in Orissa. The Collector of Balasore reported that the rainfall on the Orissa hills was extraordinarily heavy, and caused high floods in all the rivers in his district, which inundated all the low-lying lands. Strong southerly winds continued over the whole of the centre and north of the Bay during the day.

September 23rd.—The centre passed through the districts of Ranchi and Hazaribagh in the early morning of the 23rd, and was between Dehri and Hazaribagh at 10 A.M. The storm had, however, almost filled up by this time, and it existed for some hours longer as a diffused disturbance which advanced northwards into north Bihar, where it finally broke up completely in the morning of the 24th. The strongest

winds in the Bay in that day were only of force 3-4, so that the weather in the Bay had reverted to its normal character at the end of September.

The storm wave.—The storm wave inundated the whole of the low land in the neighbourhood of the False Point harbour. High water was due at about 8 A.M., so that the storm wave which accompanied the central depression and calm area preceded the tidal wave by about two hours. The storm wave came up at 6-20 A.M. and swept over False Point harbour, destroying all the houses ashore. It passed over Jumbo at the entrance to the canal, and then rolled in one wide unbroken wave in a north-easterly direction over Kaldeep and Kerara, submerging villages and carrying away before it, with irresistible force, houses, cattle, human beings, *etc.* The trees were rendered leafless and scorched as if by the blast of a furance. The measured height of the wave above mean sea level was 22 feet at False Point and 21 feet at Jumbo. The effect of the tidal wave was suddenly to create a sufficient depth of water all over the harbour sufficient to float large steamers. The *Booldana* was carried over shoals where there is ordinarily at high tide only a few feet of water.

THE BACKERGUNGE CYCLONE OF 27TH OCTOBER TO 1ST NOVEMBER 1876.

The Backergunge cyclone was the largest and most destructive to life that occurred in India during the 19th Century.

Brief summary of chief facts.—The following gives the most important details of the storm :—

The cyclone apparently formed on the 25th, 26th and 27th to the west of the Andamans in Lat. 10 N., Long. 89° E., and moved first northwards and then gradually recurved to northeast. The position of the centre at various times and its average rate of motion are given below—

Date.	Position.		Distance passed over since last previous position.	Average rate of motion during interval.
	Latitude.	Longitude.		
27th, noon	10° N. ..	89°E. ..	90	4 miles per hour.
28th, noon	11½°N. ..	89°E. ..		
29th, noon	13°N. ..	89°E. ..	120	5 ,,
30th, noon	14½°N. ..	89¼°E. ..	105	4 ,,
31st, 1 P.M.	18° 45′N. ..	89° 25′i ..	204	12 ,,
31st, 6 P.M.	19° 45′N. ..	89° 50′E. ..	75	15 ,,
31st, 9 P.M.	20° 30′N. ..	290° 25′E. ..	62	21 ,,
1st, 3 A.M.	22° 30′ N. ..	91° 0′E. ..	144	24 ,,

One of the more remarkable features of the storm was the very great increase of its velocity on approaching the coast of east Bengal.

It reached the mouth of the Megna about 3 A.M. of the 1st of November. The central calm was then from 15 to 18 miles in its longest diameter, and was probably elliptically-shaped the longest diameter being nearly perpendicular or oval to the direction of motion.

The cyclone was completely broken up before 10 A.M. of the same day by the action of the hills in eastern Bengal and south Assam. It extended, at sea over a very large area, blowing with hurricane force, and disabling vessels at a distance of 200 miles from the vortex, and was the most extensive as well as one of the fiercest cylones of the century.

The lowest readings of the barometer observed during the storm were :—

28·15″ (uncorrected) on board the *Tennyson* (20 miles to west of centre).
28·15″ (uncorrected) on board the *Lady Octavia* (20 to 25 miles west of centre).
28·2″ (uncorrected) on board the *British Statesman* (20 miles west of centre).

It is hence almost certain that the barometer was below 28 inches in the central area, and may have been at least as low as 27·5 inches, or even lower.

Weather previous to the formation of the cyclonic storm.—The mean temperature of the air was from 2° to 7° below the average of the season in northern India, but was slightly above it at Port Blair and Madras, and probably over the south and centre of the Bay, where the weather was very sultry. Fine dry cool weather, with cloudless skies and light airs, prevailed almost without interruption in northern India. During this period the winds in Bengal which had been previously southerly, shifted round to their cold weather directions and the winds and weather at the end of the third week of October were such as prevail when the northeast monsoon is fully established over the north of the Bay. Pressure was remarkably uniform over the Bay, and in northern and central India.

From the 20th to the 27th or 28th the weather in north of the Bay was of the same character as in Bengal. In the southeast of the Bay, as is indicated by the Port Blair, Nancowry and ship observations weather was unsettled, and the winds were very variable and unsteady. Much rain was falling, and squalls were of occasional occurrence. No change took place in that area of slightly unsettled weather until the 24th and 25th. The cyclonic movement was comparatively feeble between the 24th and 26th. On the evening of the 25th and morning of the 26th a rapid and significant increase took place in the force of the wind at the Nicobars, which was coincident with the commencement of rapidly increasing cyclonic circulation on the large scale over the centre of the Bay. The history of the storm proper hence dates from the evening of the 25th.

History of the Storm.—*October 27th.*—The observations of the 27th show that there was a clearly marked depression, the centre of which was to the west of the Andamans in Lat. 10 N., Long. 89°E., and that over this area winds were cyclonic in direction, but were as yet of moderate intensity. The ships *Empire of Peace* and *British Sceptre* were to the southeast of the central depression during the day. The former experienced thick cloudy weather, much rain and moderate winds from southsouthwest to southwest. The latter (nearer to the centre) had strong breezes during the day and a deluge of rain. The *Arabia* to the west of the centre had constant rain and occasional squalls. The ships *Tennyson* and *Forfarshire* (250 miles to the northnorthwest) had fine clear weather with moderate northeast winds. Moderately strong cyclonic winds were blowing at Port Blair and Nancowry. Skies were thickly clouded, and heavy rain fell during the day.

October 28th.—The cyclone developed rapidly in intensity and extent on the 28th. Torrential rain fell over a large part of the area of depression, and frequent squalls occurred, and the winds near the centre strengthened rapidly. The *British Sceptre*, 200 miles to the eastnortheast of the centre, had torrents of rain at noon, the *Empire of Peace* (180 miles to the eastnortheast at noon) strong breezes with much rain, and the *Allahabad* (150 miles to the eastnortheast) constant rain and heavy squalls. The *City of Venice*, to the westsouthwest of the centre at noon, had frequent squalls of wind in the morning. At noon there was a fresh breeze, with heavy squalls. At 8 P.M. the wind had increased to a fresh gale, and at midnight it blew a hard gale, with hard squalls.

October 29th.—The centre of the depression advanced during the 24 hours preceding noon of the 29th to Lat. 13°N., Long. 89°E., or a distance of about 120 miles and was nearly 150 miles due west of Port Blair. The area of depression at mid-day of the 29th covered a large area, extending from Lat. 6°N. to Lat. 18°N., and from Long. 92°E. to Long 83°E. in which winds were of force 6 or upwards, and squalls were experienced. The ship *British Sceptre* (250 miles to the northeast of the centre at noon of the 29th) experienced torrents of rain and hard squalls, the *Allahabad* (270 miles to the northeast) constant rain with very heavy squalls, and the *City of Venice* (280 miles to the westnorthwest of the centre) had an increasing gale with continuous rain during the morning. The captain of the *City of Venice*, states that the winds and squalls increased in force, and that at 4 P.M. it blew a hard gale, with furious squalls. The logs of several vessels, which were approaching the mouth of the Hooghly at this time describe the weather as threatening in the north of the Bay, and show that strong winds and squalls were felt as far north as Lat. 18°N. in the morning. Before nightfall the weather had become unsettled and squally as far north as Lat. 20°N., and the appearance of the sky was such as to suggest the speedy occurrence of stormy, cyclonic weather.

October 30th.—The full development of the storm took place during the evening of the 29th and morning of the 30th. The land observations and the ships' logs show that

on the morning of the 30th violent cyclonic motion of the air (in which winds of force 9 to 12 with frequent hard squalls obtained) extended over an elliptical shaped area (250 miles by 200 miles), the centre of which at noon was in about Lat. 14½N., Long. 89½°E).

October 31st.—The steam-ship *Penang* was involved in the storm on the morning of the 31st. She left Calcutta, on the 28th and steamed southwards into the teeth of the advancing cyclone. She experienced very rough weather on the 30th. The wind increased rapidly, and the barometer began to fall quickly on the evening of the 30th, and was at its lowest at 4 A.M. of the 31st. At 6 P.M. of the 30th the ship was taking huge seas on board, and the deck midship house and port saloon flooded with water. At 10 P.M., the engineer and engine-room crew were battened down below, and the fore and main rooms and mizen gaff were blown adrift. At 4 A.M. of the 31st the gig was washed away. Wind and sea were then at their highest and it was impossible to walk or stand on deck. At 7-30 A.M. the whole of the front of the saloon was stove in. The ship lay like a log, with the saloon full of water. All the head-boards, knees, and gangways were now washed away. The barometer was at its lowest (29·32″) from 4 A.M. to 7-30 A.M., and the weather began to improve at 8 A.M. The ship was, however, found on the 1st to be a complete wreck on deck and it was judged necessary to put back to Calcutta. The *Penang* was at 7 A.M. of the 31st, when nearest to the centre, at a distance of about 150 miles from it.

The *Tennyson* was about 20 miles to the west of the storm centre at 1-30 P.M. on the 31st. She was proceeding up the Bay to the mouth of the Hooghly along the meridian of 89°E. in front of the storm on the 29th and 30th. . She had passed through the area in which the storm was generated only a few days previously and began to experience squalls and increasing winds on the afternoon of the 29th. Weather became steadily worse on the 30th, and at 10 P.M. it blew in furious squalls for an hour. This was followed by a brief lull, when a very violent squall from the eastnortheast threw the ship on her beam ends until the first rush of the squall was past. The wind blew with hurricane force from the eastnortheast from midnight (when the barometer was 29·6″) until 9-30 A.M., when it veered gradually to north, and the noise of the wind became a perfect howl. The sails were now torn from their gaskets and went to ribbons in a few minutes. The sea was a scene of the wildest confusion. The ship was thrown on her beam ends, and the sea, breaking on board, swept away everything and left her a wreck on deck The barometer was lowest at 1-30 P.M., when it stood at 28·15″ (corrected reading 28·82″). The weather began to moderate at 6 P.M., and at midnight it had died away to a calm. The top of the sea was blown about during the storm so as to make it impossible to see 20 yards from the ship.

The *Lady Octavia* and *Palmas* were nearest the centre at 6 P.M., when it was in Lat. 19°45′N., Long. 89°50′E., and advancing at a rate of 15 miles per hour in a northnortheasterly direction. The former was then about 25 miles and the latter 35 miles to the west of the centre.

The *Lady Octavia* was, on the 29th, sailing northwards to Calcutta, and was at noon in Lat. 19°33′N., Long. 90°14′E. She had heavy rain and variable winds on that day. The weather became rapidly worse on the 30th, and towards evening she was turned southwards. The barometer at 2 A.M. of the 31st stood at 29·8″ (uncorrected). At noon the wind was blowing with hurricane force, and a fearfully high and cross sea running. At 5 P.M. the main topsail blew to pieces.

The experiences on board the ship *Palmas* are valuable and interesting. The following give the most important extract from her log :—

"Left Negapatam on the 12th October bound for Calcutta, and was near the Eastern Channel light-ship on the 30th. At midnight the barometer began to fall rapidly, and the weather looked very threatening, and all preparations were made for a strong gale. At noon of the 31st it was blowing a hard gale. By this time found it must be an approaching cyclone. The ship was evidently in the northwest quarter of a cyclone, travelling from southsouthwest to northnortheast. At 2 P.M. the heavy sea and lurches (assisted by the quantity of water gone below) caused the sand ballast to shift to starboard, giving the ship a heavy list to leeward. With the heavy lurching the 90 fathoms of starboard chain broke adrift, and was thrown on the lee gunwale, and at the same time all the sails and provisions, etc., on the weather side of the fore cabin were thrown to leeward, throwing the ship almost on her beam ends. We slacked away fore and main

topsail sheets to try and right her, the fore one blowing away in the act, and had to slack off the main topsail sheets till it blew away. We squared the main and cross-jack yard and put the helm up to try and put her on the other tack to get the low side up, although we were already on the right tack for the cyclone, but the ship would not pay off, but continued to come up as the wind was hauling more northerly and causing the heavy southsouthwest sea to break in over our lee rails and poop, and endanger the safety of the ship by knocking against the hatches. When in this position, cut away topgallant back stays, the masts going over with their gear and fouling the topsail yards. We could not cut them clear, as all the wire got twisted and turned together. At 4 P.M. the cyclone was increasing; barometer 28·50″, the sand still shifting to leeward and putting the ship on her beam ends. I saw then that the next thing to cutting the masts away would be to let go the starboard anchor, and let it run the 90 fathoms chain from the lee side. I went forward with the chief officer and saw all clear, and let it go, taking the 90 fathoms chain with it. The ship then righted a great deal, and less sea came over the rails. We then had a chance to go below to trim some of the ballast, and I sent all hands below for that purpose, leaving the carpenter, sailmaker, and one man on the deck to look out for the hatches and tarpaulins. In the meantime the top-gallant masts and yards were swinging about and cutting the topsails and courses adrift from the gaskets and causing them to be blown away. At 6 P.M., when the barometer stood at 28·20″, we had the heaviest blow. The centre of the cyclone was then passing about 40 miles" (this was the captain's estimate and almost exactly correct) "to the eastward, the wind hauling to northnorthwest and northwest with fearful vivid flashes of lightning, thunder, and rain. At this time the whole of the remains of our sails were blown away. The foretopgallant yard had by this time got down, end on alongside, and knocked against the side and chafed very much, but could not cut it clear. At 7 P.M., the gale bating, we ceased trimming, the men being all tired and worn out, and the southsouthwest sea being then nearly aft, ship heading up northeast by north and rolling much less. 3 P.M., gale moderating and, the barometer having risen to 28·50″, let all hands go to rest and get ready for the next day's work, to clear the wreck and trim ballast. Midnight, the weather clearing and wind moderating".

The British India Steam Navigation Company's steamship *Moulmein* left Chittagong for Calcutta on the afternoon of the 30th. She hence crossed directly in front of the advancing storm. The following gives the chief details of the storm as experienced on board :—

"Noon of the 31st.—Wind northeast, with heavy confused sea. 4 P.M.—Wind now blowing a hurricane. 5 P.M.—Fore-topmast carried away. 7 P.M.—Foremast carried away close to deck. Spray blowing right over the ship; standard and steering compasses blown away. 10 P.M.—Wind northnortheast. Funnel carried away. Main topmast carried away. Fires put out and the boiler ran dry. The engines not able to work, and three feet of water in the stokehole, with all pumps choked. The barometer at 8 P.M. was 28·4″, the lowest reading taken. From 11 P.M. the wind began to decrease".

The *Allahabad* was about 80 miles from the centre in the opposite quadrant to the *Moulmein* at the time when that vessel was nearest to it. Her log states :—

"At noon of the 30th, when in Lat. 17°57′N., Long. 91°40′E., constant rain was falling, with frequent very heavy squalls. A very heavy swell came up from southsouthwest and southwest. 8 P.M.—Weather looked bad and threatening, with every indication of a cyclone. At 11 P.M. it was blowing a heavy gale from eastsoutheast, and a strong current setting northwards. At midnight it was blowing a very hard gale with constant rain, very heavy squalls, and much lightning to the southward. The squalls increased in force during the morning of the 31st, and at noon the cyclone commenced to blow with great fury and continued with no abatement until midnight. At 8 P.M. the wind began to veer to southeast. At 10 P.M., when the wind was at southsoutheast to south, the cyclone was at its fiercest. It was then blowing with inconceivable fury. The sails were torn from their gaskets, and the canvas in the mizen rigging blown away. The wind began to moderate after midnight, and the sea went down fast, and at noon on Wednesday, the weather was beautifully fine".

The centre at 9 P.M., about which time it was nearest to the *Moulmein*, was in Lat. 20°30′N. and Long. 90°25′E., and had been moving during the previous three hours at

the rate of 21 miles per hour in a north-easterly direction. It continued to advance with accelerating velocity.

November 1st.—One peculiarity of the Backergunge cyclone was the rapid increase in its rate of advance as it marched northwards, more especially on the 31st. During the last five or six hours before it struck the coast it was marching at the mean rate of about 22 miles. It struck the coast at the mouth of the Megna. The centre passed over the island of Huttyah between 3 and 3-30 A.M. over the island of Siddhi between 3-30 and 4 A.M., and over the South Bamni district between 4-30 and 5 A.M. The vortex, or calm centre, appears to have been elliptical shaped, the largest axis running perpendicular to the direction of motion, and was probably 16 miles in length, whilst the shortest in the direction of motion was from 8 to 10 miles in length.

The later history of the Backergunge cyclone is unusually brief. The centre passed over Noakhally at about 4 A.M. and over Dewanguni at 5 A.M. where the calm interval was very short. It was then advancing in a northeast direction to the Tipperah hills. They lay at right angles to, or across, the direction of motion of the approaching cyclone, and acted not only as a perfect barrier, but as an obstruction which completely broke up the cyclonic motion before 10 A.M. of the 1st.

The storm wave.—The most remarkable feature of the Backergunge cyclone was the enormous storm wave which it drove over the islands and low lands at and near the mouth of the Megna. The inundation was due to an unusually high tidal wave, followed very shortly afterwards by the storm wave. It was full moon on the evening of the 31st, and there was hence a spring tide which flooded the low-lying land at the head of the Bay. High water was due at Chittagong at 0-30 A.M., and in the mouth of the Megna from 1 A.M. to 2 A.M. The pressure of the advancing storm wave prevented the tidal and river water flowing off. The storm wave was hence retarded over the shallow water near the entrance to the Megna and accumulated there and finally overpowered the down-flowing waters, and rushed with irresistible force over the islands, and low-lying coast districts, covering them to the depth of from 10 to 30 or 40 feet in the course of a very short space of time, probably less than half an hour. The waters receded very quickly as the storm passed inland and began to break up, and at 8 A.M. they had entirely retreated, after having destroyed all the crops and drowned a very large proportion of the inhabitants. The first estimate of the destruction of the life was given as about 200,000. A later, and probably more correct, account puts the loss of life by drowning at 100,000, and the loss subsequently by disease (chiefly cholera), directly due to the inundation, as 100,000.

THE PORT BLAIR CYCLONE OF 1ST TO 7TH NOVEMBER 1891.

This storm is of great interest, more especially on account of the following features :—

(1) It originated in the Gulf of Siam outside the Indian area. It advanced across the Malayan Peninsula into the Andaman Sea and Bay of Bengal. It is the first cyclone in the Bay on record of which there is clear and decisive evidence that it originated outside the Bay.

(2) The storm was in its earlier stages of small extent although of great intensity. The storm winds were hence of extraordinary violence, in this respect resembling the False Point Cyclone. The storm increased in extent without altering in intensity as it approached the head of the Bay. It had an existence of at least nine or ten days and was during upwards of seven days an intense cyclone.

Origin of the storm.—The storm is known to have crossed the Gulf of Siam on the 30th and 31st of October. It is probable that the storm originated in the Gulf of Siam on the 28th and 29th of October and that it had developed into a small cyclonic storm of considerable intensity on the morning of the 30th, when as shown by the available information, it was moving westwards across the Gulf of Siam.

History of the storm.—According to the few reports of the storm* received from Siam the cyclone was fully developed on the 30th, and advanced over the Gulf of Siam along a westerly course on the 30th and 31st.

The storm crossed the Malayan Peninsula during the night of the 31st and almost completely wrecked the towns of Bandon and Chaiya, the latter being one of

*It is now known that this was a typhoon which formed to the south of Palawan between the 22nd and 24th October and then moved in a westerly direction.

the largest towns on the Gulf of Siam The storm broke out at Chaiya at 11 P.M. of the 31st and lasted until 3 A.M. of the 1st November. A storm wave flooded the town to the depth of 7 or 8 feet. Three hundred and eighty-seven religious buildings and 4,238 other buildings were more or less completely destroyed, and 109 people died by drowning or by falling houses, etc. At Renong, on the west side of the Peninsula, the storm lasted from about 1 A.M. to 7 A.M. of the 1st. The destructive part of the storm area averaged about sixty miles in breadth. The severity of the storm in this belt was very great as houses and trees, etc., were all levelled to the ground and the roads rendered impassable by the rains and fallen trees.

The storm at this stage advanced at an average rate of about 18 miles per hour, and passed out into the Andaman Sea early on the morning of the 1st November. It was of comparatively small extent, the inner area of hurricane winds not exceeding 80 miles in its longest diameter and 60 miles in its shortest diameter at right angles to the direction of motion.

November 1st.—Pressure was very uniform over northwestern and central India. Steepish gradients obtained in the Peninsula and the north of the Bay. In the Bay (excluding the Andaman Sea) winds were slightly stronger in the northern half of the Bay than in the southern half. They ranged in force from 4 in the north of the Bay to 2 and 3 in the centre and south of the Bay

The weather over the greater part of the Andaman Sea at 8 A.M. of the 1st was fine with light to moderate winds The *S. Marpesia* passed into the storm area in the afternoon. She had light winds at noon. Winds began to increase very rapidly at 3 P.M. and blew with hurricane force from 9 P.M. to 3 A.M. of the 2nd. The wind carried away the jib-boom and fore-top-mast head at 3 P.M. and the fore and main topsails and fore topmast staysail at 9 P.M. She had continuous rain during the evening and night. The corrected reading of her barometer at midnight was 28.85″ at which hour the centre was probably not more than 10 or 15 miles to the eastnorth-east.

November 2nd.—The cyclone passed over Port Blair between 2 and 3 A.M. of the 2nd and then crossed out from the Andaman Sea into the Bay of Bengal.

The data show that no change had as yet occurred in the north of the Bay. Fine clear weather, with moderate northeast winds, obtained over the whole area to the north of Lat 18°N Winds were of average force 4·1 as compared with 3·5, the normal force in November. The northward extension of squally weather was shown by the fact that the vessels between Lat. 8°N. and 20°N. and to the east of Long. 88°E. had cloudy weather with occasional showers and squalls in the afternoon and evening.

Weather in the south of the Bay had changed considerably during the previous 24 hours and was now squally with much rain and with moderate southwest to west winds. The mean force of the winds experienced by seven vessels to the south of Lat. 8°N. in the morning was 3.7, whereas on the morning of the 1st, the average was only 2.0. The data hence show clearly that moderate southwest winds now prevailed in the south of the Bay, where on the 1st and preceding days calms and light and variable airs had obtained. The weather was also more or less squally, and the squalls increased in severity during the day. The data are not sufficient to show clearly how far these squally winds extended up the southeast of the Bay, as there is no information available for the area between Lat. 8°N. and 11°N. It is, however, very probable from the rapid changes in the winds and weather that this extension was due to the action of the storm, and that the humid southwest winds of the south of the Bay now extended northwards as far as Lat 12°N. in the southeast of the Bay, and were feeding into the storm.

The cyclone passed over Port Blair early on the morning of the 2nd. The observer, Mr. Carroll of the Medical Department, who was then the meteorological observer at the Port Blair Observatory, took a valuable series of observations during the storm, and also supplied information from various sources.

The following is Mr. Carroll's account of the storm :—

"On the afternoon of the 1st instant, at about 2 P.M., rain clouds, banking up from the east and northeast, soon overspread the sky and burst, attended by strong

wind. After a good shower, registering 0.60 inch of rain, the wind abated, leaving the usual gloomy state of weather experienced on a monsoon day. During this shower I noticed that there was some disturbance in the upper currents of air ; for, the lower clouds—though moving chiefly from eastnortheast, were very frequently unsettled, seeming to falter, circle and then move on—the wind-vane at that time was oscillating between north and eastnortheast. However, at 4 P.M. the wind having fallen, to all ordinary appearance mischief was not expected. About 1 A.M. on the 2nd instant the wind rose in fierce gusts from the north. This was the first indication of coming trouble. My barometer registered 29.602″ at 1 A.M. The mercury continued to fall ; at 2 A.M. it registered 29.404″ ; the wind-vane circling at very great speed, and the wind so strong apparently from northeast, that I could not force my way up the ladder to the anemometer. At this time the shingles from the convict barracks and hospitals were being ripped up by the wind. The I. M. S. *Enterprise* then in harbour was either being driven or was forcing her way out at the southern entrance of the Ross Harbour, and was whistling, apparently in distress (for, as it so happened, it was their death signal). She was driven on the rocks when about halfway out, and was a total wreck, losing all but six hands, before daybreak. Between 2 and 3 A.M. there was a sudden lull, then the wind veered round to southward, and by 3 A.M. the cyclone was at its worst. The barometer reading was 28.502″ ; and, after a very hard struggle to reach the anemometer a reading was registered at 499.9. Two steam barges, several large lighters and many boats in the harbours had lost their anchorage, and were at the mercy of the wind and waves. They have all been more or less smashed or otherwise destroyed. Trees of great size were ripped up by the roots. Cocoanut-trees were broken off at the crowns like mushrooms ; areca-nut trees snapped like match-wood and the roofs and sides of nearly every building destroyed. At 4 A.M. the barometer rose to 28.680″. Another attempt was then made to reach the anemometer This was accomplished with very great difficulty, and the reading taken at 105 + 1·4 miles, so that in the hour the wind travelled (505 — 499.9) + 106.4 = 111.5 miles. The wind vane had been wrenched off. About 15 minutes after leaving the anemometer the cups were wrenched off too ; the platform and hand-rail leading to the instruments were broken off."

November 3rd.—The observations show that weather was not much changed in the south of the Bay. Skies were more clouded and winds slightly stronger. The storm was in the centre of the Bay, and its influence was extending rapidly northwards. Weather was squally, with strong easterly winds over the whole of the north of the Bay in the morning, and the winds intensified rapidly during the day.

The information when charted shows that the most probable position of the centre at 8 A.M. was Lat. 14°10′N., Long. 87°20′E.

The whole of the observations indicate that the storm area was extending and that the extension was occurring most rapidly in the eastern and southern quadrants of the storm area. This is most clearly shown by the weather experienced by the *S. S. Lincolnshire*, *Regulus*, and *Arratoon Apear*. The *S. S. Saint Regulus*, 350 miles northeast of the storm centre at noon, had hard squalls with heavy rain : the *S. S. Lincolnshire*, 300 miles northnorthwest of the centre at noon, had a stormy gale, with violent rain squalls, and at the *Arratoon Apear* 350 miles northeast of the centre at noon, had very squally weather, with strong northeast winds. It is hence evident that the area of the storm winds and gales and of severe squalls had extended to a distance of at least 350 miles to the northeast and southeast of the centre.

November 4th.—Pressure had decreased over the whole of India The fall was greatest in the Madras, Orissa and west Bengal coast districts, where it ranged from a tenth to a sixth of an inch. Skies were overcast in the north Madras coast districts, and were more clouded than hitherto in Bengal. Rain had, however, not yet commenced to fall in coast districts of north Madras or in Orissa or Bengal.

The 8 A.M. observations at the coast stations indicate that there was a largish disturbance off the coast of the Circara and Ganjam, and that the centre was probably nearest to Vizagapatam, but they give no definite information of the intensity of the storm The most noteworthy features of the observations were the very dry northwest winds at Cocanada and Vizagapatam, and the absence of rainfall in the outer area of the disturbance.

The 4 P.M. observations show that winds were unchanged in direction at these coast stations, but that their force was increasing rapidly at False Point and Saugor Island, due chiefly to the extension of the storm area during the day.

The storm did not affect the weather at Vizagapatam on the 4th to any important extent. Weather was unsettled and sea rough, but the northwest winds gave clear skies during the greater part of the day.

The marine data show that weather was very squally with strong southerly winds in the eastern half of the entrance to the Bay. It was fine and clear with light to moderate winds off the east Ceylon and Coromandel coasts and also over the greater part of the Andaman Sea. Weather was more or less disturbed over the centre of the Bay, and squally weather had now extended to the head of the Bay. The light vessels reported squalls and fresh ENE winds in the morning. Weather was gloomy and skies overcast with northeast winds in south Bengal.

November 5th.—The 8 A.M. observations indicate that the cyclone on the morning of the 5th covered Ganjam and Orissa and the adjacent portion of the Bay area. The barometric readings and wind data at the coast stations showed that the storm was one of very considerable extent and intensity. The centre at 8 A.M. was about 10 miles east of Puri, and hence off the south Orissa coast. It was advancing in a northeasterly direction towards False Point.

The marine observations show that conditions were unchanged in the south of the Bay, where light to moderate winds obtained and weather was generally fine and cloudy. Occasional squalls were experienced, e.g., the *S. Eurydice* in Lat. 11°N., Long. 91°20′E., had squally weather during the day and the *S. Joseph*, in Lat. 14°25′N., Long. 91°50′E., had squalls with heavy rain, in the morning.

In the centre and north of the Bay cyclonic winds of indraught prevailed, and were of force 8 and upwards between the 18th and 21st parallels of latitude and to the west of the 90th meridian. The storm area was hence much larger than on the 2nd and 3rd, and had increased considerably in extent during the previous 24 hours, and at the same time the storm had not diminished in intensity.

The storm centre passed a little to the east of Gopalpur and Puri during the morning and over False Point in the afternoon. It advanced about 25 miles to the east of Shortt's Island at the mouth of the Dhamrah river late in the evening. The following gives the accounts of the storm as experienced by the *Lady Agnes* and at these stations.

The *Lady Agnes* began to experience strong cyclonic winds on the morning of the 3rd, when she was at least 350 miles to the north of the centre. She drifted westwards during the day near the south Orissa coast. On the morning of the 4th when she was about 200 miles to the north of the centre, she experienced a hard gale with hard squalls. The centre on the 4th recurved through northnorthwest to northnortheast and rapidly approached the ship *Lady Agnes*. In the evening the wind had increased to a terrific gale from eastnortheast. At 1 A.M. of the 5th, when the vessel was probably off the Ganjam coast east of Gopalpur, it was necessary to cut away the foremast. She was nearest the centre between 3 A.M. and 1 P.M. at which time she had hurricane winds with a tremendous sea. She was then probably not more than 15 or 20 miles from the centre. She was carried rapidly under the force of the winds and storm currents from the west to the southeast quadrant of the cyclone, and was gradually left behind on the morning of the 5th. Hence weather rapidly improved, and she had moderate winds and fine weather on the afternoon and evening of the 5th.

The storm at Puri began at 10-30 P.M. of the 4th, and lasted until 1-30 P.M. of the 5th. During this period 13 inches of rain fell. The observer also states that the wind blew at the rate of 96 miles an hour at 9 P.M. of the 4th. This, however, is very doubtful. He also adds that it blew most heavily between 7 and 10 A.M. of the 5th, when it was utterly impossible to take readings of the anemometer on account of the violence of the wind. The anemometer was blown away shortly after 10 A.M. The wind was from northeast during the greater part of the storm and shifted rapidly to westnorthwest between 7 A.M. and 10 A.M. Much damage was done to houses and many lives are reported to have been lost in the Chilka lake by the upsetting of boats.

The storm centre passed over False Point in the afternoon between 4-05 P.M. and 4-45 P.M. Two series of observations are available, one taken by the observer at the light-house and the other by the Port Officer.

The central calm area passed over the light-house between 4-05 and 4-45 P.M., and hence lasted 40 minutes. As the storm was progressing at the rate of nearly 9 miles an hour, the greatest diameter in a north and south section was between 5 and 6 miles. The Port Office was just on the outer western edge of the calm centre. The Port Office bears northnortheast (*vide* Taylor's Directory) from the light-house.

The False Point observations throw light upon several interesting features of cyclones. The following are the most noteworthy points :—

First.—The passage of the calm central area over the light-house lasted more than half an hour, and hence afforded ample time to test the pressure and air motion conditions in and near the calm area. The calm lasted from 4-05 P.M. to 4-45 P.M. As described by the observer, the wind, which was blowing a moderate gale at 4 P.M., fell to a dead calm at 4-5 P.M. The transition was hence abrupt, but less so than is usually indicated by the remarks in the logs of ships that have passed through the central calm area of cyclones. The dead calm was followed by light variable winds until 4-45 P.M. after which the wind increased very rapidly and was blowing with hurricane force at 5 P.M. These observations hence indicate that the transition from the central calm to the hurricane winds just outside the central calm area is less rapid than is usually supposed, and that the change is rapid and gradual, rather than abrupt and spasmodic.

The False Point Port Officer added the following remarks to the observations which he forwarded :—

"I would also beg to say that this has been one of the most severe cyclones that I have experienced during my long residence of 26½ years at False Point. The whole of the station except the refuge building, is in ruins, but I am happy to say that no lives have been lost."

"The whole of the beacons marking the harbour have been blown away and Reddie Head Sand Spit has entirely disappeared. Yesterday afternoon I pulled across in my boat what used to be dry sand and found nothing less than 6 feet of water".

The keeper of the light house on Shortt's Island at the entrance to the river Dhamrah (in Lat. 20°47′N., Long. 86°50′E.) took a most valuable series of observations during the storm. The station was about 16 miles to the north of the centre when nearest to it about 8 P.M. and hence within the inner storm area of hurricane winds.

The following is his account of the weather on the 5th :—

November 5th.—From midnight to 6-0 A.M. the squalls continued with unabated force and frequency, but the rain was not heavy during this time. During a lull which occurred between 6-0 and 6-10 A.M. the wind shifted to E by S, followed immediately by a terrible rain squall. At 6-40 A.M. wind backed to NE. During the lulls after the squalls the wind veered to ENE and backed to NE on the approach of the next squall. 8-0 A.M. no change in the frequency or violence of the squalls ; blinding rain prevailing. Between 8-0 and 9-0 A.M., after the squalls the clouds broke to windward and after this the sky again became entirely overcast and squalls increased in violence ; wind still unsteady. From 11-0 to 11-10 A.M. the sun shone brightly, the interval being between two squalls ; afterwards the sky became overcast and very wild-looking, and squalls more violent with heavy rain. At noon I noticed that the sea level had fallen about 4 feet in the space of about half an hour ; no apparent change in the weather. From noon to 3-0 P.M. squalls one after the other in quick succession of terrific violence with hard rain. At 3-20 P.M. wind shifted to E by S, squalls still most terrific. From 4-0 to 5-0 P.M. the appearance of the weather was most terribly wild ; all persons took refuge in the light-house at this time. From 5-0 to 10-0 P.M. a hurricane from ESE, with incessant heavy rain and lightning ; 10-10 P.M. weather suddenly moderated to fresh breeze, but gusty. At 10-50 P.M. the wind shifted to N blowing a very strong gale, but gusty with light rain and lightning, Barometer rising rapidly and pumping very much. Midnight, no change.

November 6th.—The various observations indicate that the centre had continued to recurve slowly during the night of the 5th, and at 8 A.M. of the 6th, it was crossing the coast of the Sunderbuns some distance to the east of the Saugor Island and marching in an eastnortheast direction.

Skies were now overcast over the whole of Bengal and Assam and also in south Bihar and Chota Nagpur. They were partially clouded in north Bihar and the eastern districts of the United Provinces, and were clear over the whole of northwestern and central India. Very heavy rain had fallen in Orissa during the previous 24 hours.

The chart giving the 8 A.M. distribution of pressure of this day shows that the storm centre at that hour was due east of Saugor Island, at a distance of between 30 and 40 miles.

The observations appear to indicate that the storm was already beginning to break up. Strong winds were blowing at Saugor Island and Calcutta nearest to the centre. These stations occupied the same position at this time relative to the centre that Gopalpur had done about 24 hours previously. The winds at these stations at 8 A.M. were very much feebler than at Gopalpur their velocity being not more than one-half or one-third that at Gopalpur on the previous morning, when it was nearest the centre. The winds at Barisal, Dacca and Jessore in east Bengal in the northeastern quadrant, were comparatively feeble, and Barisal reported a calm at 8 A.M.

The storm centre at 8. A.M. was about 35 miles to the east of Saugor Island and at 4. P.M. was a little to the southeast of Dacca. As it had passed over False Point between 4 P.M. and 5 P.M. of the preceding afternoon, it advanced across the northwest angle of the Bay during the night. The light vessels and pilot vessels and a number of vessels which had arrived at the Sunderbuns during the previous 48 hours, and were cruising about, waiting for the bad weather to pass away in order to obtain pilots and proceed up the river to Calcutta, were all involved in the storm during the night and experienced hurricane winds and a tremendous sea.

The *V. P. Coleroon* which had passed through nearly every cyclonic storm of the previous 20 years, foundered during the night off the Orissa coast.

The storm centre passed over the *F. L. V. Canopus* at 2-30 A.M. of the 6th. She was stationed at the *Intermediate Station* (Lat. 21°14′N., Long. 88°11′E.) 30 miles to the SSE of Saugor Island.

Captain Beahan describes the weather he experienced as follows :—

"The 5th commenced with a brisk easterly gale and high sea, but as the day advanced the wind increased in force, the sea became more confused and the blinding heavy rain squalls more frequent. By 4 P.M. it was blowing a hard gale, wind veering from east to eastsoutheast in the squalls, and at 10 P.M. it had settled and remained steady at east till 2-30 A.M. on the 6th, when it suddenly fell calm, the calm lasting not more than from 3 to 4 minutes. At this time the wind shifted suddenly into the westnorthwest and blew with terrible force. In all my experience at the Sandheads during the last 16 years, I have never seen anything like the heavy rain thunder and lightning, terrible sea and force of the wind that we experienced in the storm.

"From 10 P.M. on the 5th to 3-30 A.M. on the 6th, it was blowing with most terrific force and the sea very high and confused. At 2-20 A.M. just before the centre passed over us, the vessel heeled over the starboard, putting main and other hatches in the water. We then parted a 20-inch coir cable, and were driven from our station. We remained in the above position, vessel heading eastsoutheast till 3-30 A.M., the terrific sea sweeping over us. When it moderated I brought the vessel up, and at daylight found myself near the South Channel, being 18 miles southwest off my station. I observed a number of wrecks of vessels floating about bottom up, and in pieces, and the sea covered with wreckage".

November 7th.—The depression at 8 A.M. was in the Cachar district of Assam and adjacent districts, but it was now very slight and of little importance.

The breaking up of the storm accompanied a rapid clearing up of the skies during the night of the 6th.

Intensity of the storm as gauged by the maximum depression of the barometer.—The following give the lowest barometric readings actually observed in or near the calm central area on different dates :—

	Date.	Position with regard to calm centre.	Barometer corrected and reduced to sea level and constant gravity.	Variation from normal of day.
Port Blair	2nd—2 A.M. ..	9 miles from central area.	28·254	—1·55
	3 A.M. ..	5 miles from central area.	28·359	—1·43
Puri	5th—6 A.M. ..	25 miles from central area.	29·068	—0·77
False Point Light-house ..	5th—3·45 P.M.	2 miles in front of calm centre.	28·012	—1·83
False Point Port-Office ..	5th—5 P.M. ..	Just outside the calm centre.	28·190	—1·66
Shortt's Island	5th—8 P.M. ..	25 miles north from the calm centre.	29·028	—0·86
Intermediate station	6th—2·0 A.M.	In calm centre ..	28·670	—1·22
Lena	6th—1·15 A.M.	In calm centre ..	28·000 ?	—1·89
Lincolnshire	6th—2 A.M. ..	5 to 10 miles from calm centre.	28·860	1·03
Japan	6th—2·20 A.M.	20 to 30 miles from calm centre.	29·150	—0·78

Magnitude of the storm.—The whole of the data strongly support the inference that the inner storm area was practically unchanged in shape and extent from the evening of the 31st to that of the 5th. It was almost certainly elliptical-shaped throughout, its largest diameter averaging 80 miles and shortest diameter (probably) 60 miles. The direction of its longest diameter coincided approximately with the direction of advance of the storm centre throughout its existence.

It is much more difficult to estimate the extent of the outer storm area. It is, however, certain in the present case that when the storm entered the Andaman Sea it did not affect the weather and winds to any considerable extent at distances of 100 miles to the north and south. As it advanced over the Bay the area of strong winds and squally to stormy weather increased largely in extent. The extension occurred chiefly in the eastern and southern quadrants, where the indraught to the cyclonic storm intensified the southwest monsoon humid winds. For example, on the 5th, winds of force 8 (moderate gale) were experienced at distances of at least 300 to 350 miles from the centre in these quadrants.

Hence the important inference that the calm central area and the inner storm were almost unchanged in extent, and in several other characteristic features from the 1st to the 5th, but that a very considerable extension occurred during this period in the outer storm area. The extension was greatest and most marked in the eastern and southern quadrant, the quadrants into which the humid winds that maintained the storm were chiefly drawn.

Calm centre—The features of the calm centre of the cyclone, as far as they are indicated by the observations taken at False Point and Port Blair, have been fully described in the body of the report. The following gives a summary :—

(1) Pressure was lowest at some little distance in front of the calm area.

(2) Pressure was not quite uniform in the calm area but increased slightly in proceeding along the diameter coinciding with the direction of advance and in the opposite direction.

(3) The air was practically, if not absolutely, calm within the calm area proper.

(4) The transition from the hurricane winds in front to the central calm was not sudden, but gradual, and similarly in the rear the transition from the calm to

hurricane winds was not instantaneous, but gradual. This is fully established by the observations, taken at the False Point Light-house.

(5) The observer at the False Point Light-house thus describes the appearance of the sky when the calm centre was passing over it. "The sky was covered with broken cloud, and there was a heavy bank to eastward".

(6) The mercury column did not pulsate in the calm area as it did outside of it in the area of hurricane winds and fierce gusts. The light-house keeper at False Point states :—

"I noticed that during the approach of the storm the pointer of the aneroid oscillated a good deal, jumping up and down fully one-tenth of an inch, and the same thing occurred when the storm was receding ; but during the time the centre was passing it remained quite steady. At one time during the approach of the storm the pointer went as low as 28·08″ with the oscillation. I have noticed a slight oscillation of two or three hundredths of an inch in other cyclones, but never to such an extent as in this one."

Rainfall.—The rainfall data of the storm hence support the following inferences :—

(1) The rainfall accompanying the storm was excessive and torrential in character whilst it was in full vigour.

(2) The rainfall diminished rapidly on the 6th whilst the storm was filling up, and practically ceased before the residual depression had disappeared.

(3) The rainfall was heaviest in the advancing quadrant, not only whilst the storm was fully developed, but also whilst it was filling up.

It is hence very probable, if not almost certain, that in the strongest blasts the velocity was certainly not less than 120 miles per hour and may have been as much 150 miles.

Secondary whirls.—A noteworthy feature of this storm was the existence of small subsidiary whirls as part of the large general disturbance. There is some evidence of the existence for a short time of certainly two—and perhaps of three—subsidiary whirls in this storm. They were observed in the following cases :—

(1) By the *S. S. Arratoon Apcar* on the 3rd, 300 miles to the southeast of the storm centre.

(2) At Gopalpur on the 5th.

(3) In the Hooghly near Saugor Island on the 5th.

Recurvature of storm.—As invariably happens when a storm recurves in the Bay, the rate of advance decreased very considerably and varied to some extent with the amount of recurvature. The velocity of the storm centre, which averaged approximately 20 miles on the 31st, 1st and 2nd, decreased to 9 miles per hour on the 3rd and 4th, and increased slightly on the 5th and 6th to an average of 12 miles for the 24 hours preceding 8 A.M. of the 7th.

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